A HAND NOTE ON

GEOLOGY & GEOMORPHOLOGY

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Course No. CE 2203

Course Title : Geology and Geomorphology.

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Reference books :

1. Physical and Engineering Geology by S.K Garg.
2. Engineering Geology by F.G. Bell.
3. Textbook of Engineering Geology by N. Chenna Kesavulu.
4. Structural geology by Robert J. Twiss and Eldridge M. Moores.

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GEOLOGY

INTRODUCTION

Geology : [2004, 2005, 2006, 2008]

Geo means earth and logos means study. So Geology means study of earth.

Geology is the scientific study of the origin, history and structure of the earth.

Geology involves studying the materials that make up the earth, the feature and structure found on earth as well as the process that act upon them.

Geology also deals with the study of the history of all life that's ever lived on or is living on the earth now, studying how life and our planet have changed over time is an important part of Geology.

Branches of geology : [2004, 2005, 2006, 2008]

Some branches of geology are:

a. General geology
b. Physical geology
c. Stratigraphy
d. Minerology
e. Petrology

f. structural geology

g. Volcanology

h. Palaeontology

i. Economic geology

j. Mining geology

k. Sedimentology

l. Engineering geology

m. Environmental geology

n. Hydrology

o. Geochemistry historical geology

p. Geophisics

q. Marine geology.

a. General geology:

It is the formal branch of geology that deals with the broad features or aspects of the earth in particular and the other members of solar family with the sun as the kingpin and sole controller.

It also deals with the principal aspects of the cosmos. The featur of the earth includes its origin, age, constitution, internal structure and the depth zone of the marine realms..

b. Physical geology: It serves as a tool to understand the physical process which moulds the earth surface. This branch or also called geomorphology or dynamic geology.

This branch deals with

i. the geometry

ii. Origin and developmental history of landforms, feature of mountains, valleys, rivers, lakes, deserts, glaciers, oceans and ground water.

It examines the materials and processes of the earth.

c. Stratigraphy: It is the branch of geology which studies rock layer and layering.

d. Mineralogy: It is a subset of geology specializing in the scientific study of chemistry, crystal structure and physical properties of materials.

e. Petroleum geology: It is the study of origin, occurrence, movements, accumulation and exploration of hydrocarbon fuels.

f. structural geology: It is the study of three dimensional distribution of rock units with respect to their deformational histories.

g. Volcanology: It is the study of volcanos, lava, magma and related geological, geophysical and geochemical phenomenon.

h. Palaeontology: It is the scientific study of pre-historic life. It includes the study of fossil to determine organisms.

i. Ecomic geology: It is concerned with earth materials that can be used for economic and industrial purposes.

j. Mining geology: It is the extraction of valuable minerals or other geological materials from the earth.

k. Sedimentology: It is the study of sediment such as sands, muds, clay and the process that result in their deposition.

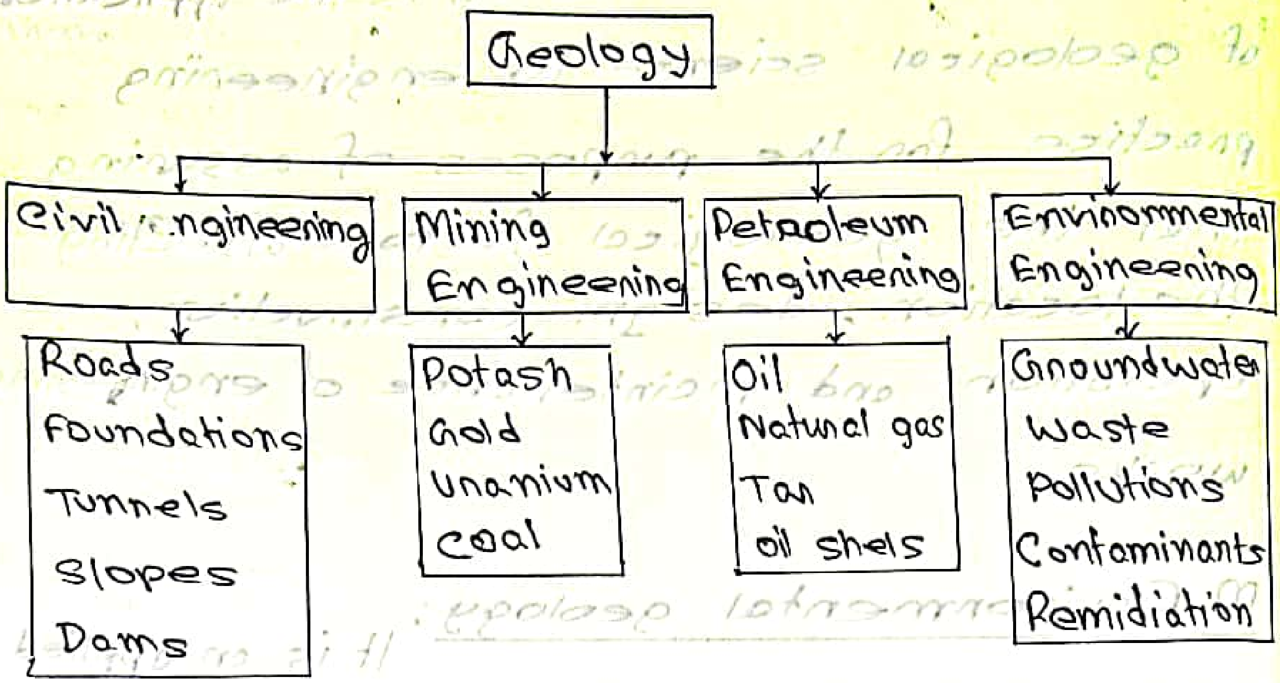
l. Engineering geology: It is the application of geological science to engineering practice for the purposes of assuring that the geological factors affecting the location, design, construction, operation and maintenance of engineering works.

m. Environmental geology: It is an applied science concerned with the practical applications of the principal of geology in the solving of environmental problems.

n. Hydrology: It is also an applied science concerned with the practical applications of the principal of geology in the solving of hydrological problems.

o. Historical geology: It examines the origin and evolution of our planet through time.

Scope of geology:



Why geology is important in civil Engineering?

[2008]

The value of geology in mining has been known but its use in civil engineering has been recognized in recent years. The importance of geology in civil engineering is as follows:

1. Geology provides a systematic knowledge of construction material, its occurrence, composition, durability and other properties.

ii. The knowledge of the geological works of natural agencies such as water, wind, ice and earthquakes helps in planning and carrying out major civil engineering works.

iii. The knowledge about groundwater is required in connection with water supply, irrigation, excavation and many other civil engineering works.

iv. The foundation problem of dams, bridges, and buildings are directly connected with the geology of the area where they are to be built.

v. In tunneling, construction roads, canals the knowledge about the nature and structure of rocks is very necessary.

vi. The stability of civil engineering structure is increased if the geological feature like faults, joints, bedding, planes etc in the rock beds are properly located and suitably treated.

VII. In the study of soil mechanics it is necessary to know how the soil mechanics are formed in nature.

VIII. The cost of engineering works will considerably reduced of the geological survey of the area concerned is done before hand.

Geology of Bangladesh: [EC]

The geology of Bangladesh is affected by the country's location, as Bangladesh is mainly a reverine country. It is the eastern two-thirds of the Ganges and Brahmaputra river delta plain stretching to the north from the Bay of Bengal. There are two small areas of slightly higher land in the north-centre and north-west composed of old alluvium called the Madhupur tract and the Barind tract and steep, folded, hill ranges of older (Tertiary) rocks along the eastern border. The downwarping of the basement rocks under central and southern Bangladesh result from the pressure of sediments that have been accumulating since the cretaceous period, mostly a large quantity of carbonate. In the Late Eocene epoch the conditions in the Bay of Bengal changed and these deposits ceased.

Uses of geological map: [EC] Geological map uses in

1. Land use planning:
a. Roads and transportation routes and facilities
b. Critical facilities siting (hospitals, schools, police, fire station)
c. Civil engineering, building codes.
d. Underground storage facilities.
e. Water treatment and water delivery systems.
f. Energy facilities
g. Protect sensitive ecosystem.

2. Geological hazards:
a. Earthquake research.
b. Landslide and ground failure research.
c. Volcanic hazards research.
d. Flooding, karst, clay-rich materials.

e. Research on human-induced geohazards.
f. Identify human health hazards.

3. Geological history:
a. Plate tectonics
b. Long term earth changes.
c. Impact by human activity
d. Paleontologic resources preservation act.

4. Water resources:
a. Groundwater development and protection.
b. Water injection and withdrawl issues.
c. Water pollution and contaminations.
d. Safe dam, reservoir and canal sites.

5. Recreational resources:
a. Selection and siting of parks and recreation areas.
b. Preservation and identification of unique geologic sites.

6. Energy resources:
a. Oil and natural gas, coal.
b. Radioactive materials
c. Renewable resources.

7. Mineral resources :
a. Metallic minerals.
b. Chemical and fertilizers.
c. Industrial minerals.
d. construction materials.

8. Waste disposal:
a. Landfill facility siting.
b. Toxic and nuclear waste disposal.
c. Sewage collection and treatment.
d. Underground facilities.

9. National defense:
a. Strategic minerals.
b. Military testing and training facilities.
c. Underground command facilities.
d. Space port facilities.
e. FEMA facilities siting.

EARTH SYSTEM

Earth:
Earth is a planet that is small and self-contained.

Parts of the earth system:
The earth is composed of several integrated parts (spheres) that interact with one another. They are -

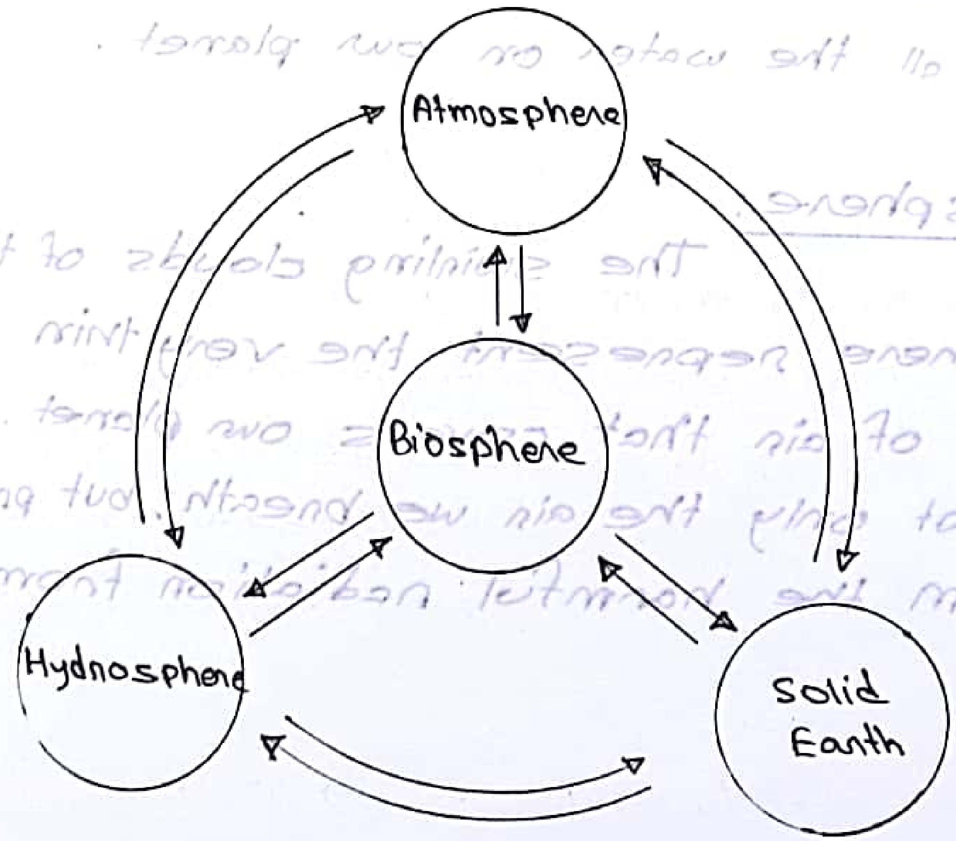
1. Hydrosphere:
The global ocean is the most prominent feature of our blue planet. The oceans cover 71% of our planet and represent 97% of all the water on our planet.

2. Atmosphere:
The swirling clouds of the atmosphere represent the very thin blanket of air that covers our planet.
It is not only the air we breath, but protects us from the harmful radiation from the sun.

3. Biosphere: It includes all life on earth concentrated at the surface. Plants and animals don't only respond their environment but also exercise a very strong control over the other parts of the planet.

4. Solid earth: It represents the mejority of the earth system. Most of the earth lies at inaccessible depths. However the solid earth exerts a strong influence on all other parts.

Dynamic interaction between the mejor parts:



Earth's internal structure:

The earth consists of three major regions marked by differences in chemical composition. They are –

1. Crust:

The rigid outermost layer of the earth is called crust. It is two types. It is only 1.4%.

a. Oceanic crust:

i. 3-15 km thick

ii. composed of basalt (Igneous).

iii. Denser than continental crust.

b. Continental:

i. Upto 70 km thick

ii. composed of a wide variety of rock types. (mafic)

2. Mantle:

i. It is middle layer of earth.

ii. comprises 82.5% of earth by volume.

iii. Base of crust to 2890 km.

iv. Mostly solid ultramafic rock.

v. Denser than oceanic crust.

vi. The montly is able to flow (plastically) at a very low rate.

vii. Mantle has several layers like lithosphere, Asthenosphere (upper), lower mantle, D-layer and the core-mantle boundary.

3. Core :

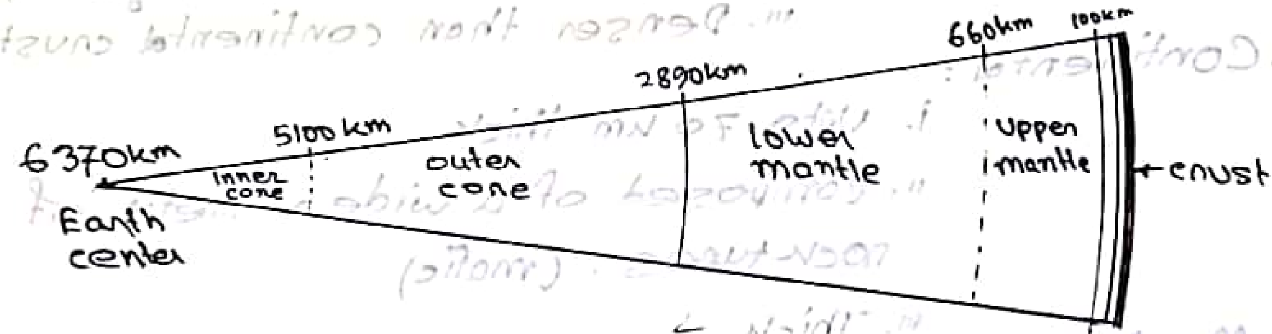
i. compost of iron, nickel and other minor elements (mostly iron) and it is 16.1% of the earth.

ii. 2890 km depth to earth center (6370 km)

iii. The outer core is liquid and capable of flow and source of the earth's magnetic field.

iv. The inner core is solid (Iron and nickel)

v. There is no major chemical difference between the outer and inner core.



Properties of mantle layers :

1. Lithosphere (crust)

i. The outer 75 km of the earth is a region which does not get heated up to near melting because it is losing heat rapidly to the surface. This relatively cool shell is called lithosphere.

ii. It is fractured into a few large plates.

iii. The movement of the plates can

deliver interior heat to the surface.

iv. It is a solid layer

v. The thickness of lithosphere is about 0-100 km.

2. Asthenosphere:

i. Thickness of asthenosphere is 100–660km.

ii. The soft region just below the lithospheric plates is called the asthenosphere.

iii. It is partially liquid

iv. It can flow like a viscous liquid.

3. Mesosphere (lower mantle):

i. The thickness is 660 – 2700 kmm.

ii. The rock in the lower mantle gradually strengthens with depth.

iii. It is solid but plastic.

iv. It is still capable of flow.

4. D-layer:

i. It is the part of the mantle within 200km of the core.

ii. It is partially liquid.

5. Core mantle boundary:

It is a depth of 2900 km.

Plate tectonics:

Plate tectonics is the scientific theory describing the large scale motion of seven large plates and the movements of larger number of smaller plates of the earth's lithosphere.

A tectonic plate (also called lithospheric plate) is a massive irregularly shaped slab of rock generally composed of continental and oceanic lithosphere.

Plate movements are on the order of a few centimeters per year about the same rate as about the same rate as fingernails grow.

The father of plate tectonics is Alfred Wegener.

Importance of plate tectonics:

The movement of the plates is the source of earthquake and volcanoes. When plates crash together it makes mountains such as Himalayas.

Why do plates move?:

Plates at our planet's surface move because of the intense heat in the earth's core that causes molten rock in the mantle layer to move. It moves in a pattern called a convection cell that forms when warm material rises, cools and eventually sink down. As the cooled material sinks down it is warmed and rises again.

Types of tectonic plates:

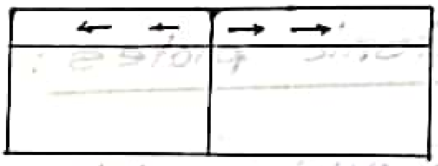
1. Major plate:
   a. African plate
   b. Antarctic plate
   c. Indo-Australian plate
   d. North American plate
   e. Pacific plate (largest plate-103300000 km²)
   f. South American plate
   g. Eurasian plate.

2. Minor plate:
   a. Scotia plate
   b. Nazca plate
   c. Cocos plate
   d. Carribean plate
   e. Juan de fuca plate (smallest plate)

Plate boundary: The location where the two plates meet is called plate boundary.

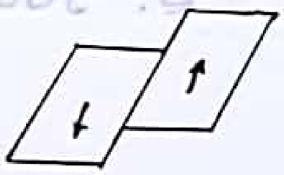
Types of plate boundaries:

1. Divergent: It occurs when two tectonic plates move away from each other. Along thes boundaries earthquakes are common, and magma (molten rocks) rises from the earth's mantle to the surface.



2. Convergent: When two plates come together it is known as convergent boundary. It causes plates to buckle up into mountain ranges and powerful earthquakes are common along these boundaries.

3. Transform boundaries: When two plates sliding past each other forms a transform plate boundary. Earthquakes are common.



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EARTHQUAKE

Earthquake/Earth tremor : [2013,2015,2016]

Earthquake is defined as the vibration of the ground due to sudden release of energy accumulated in a deformed rock.
A sudden and violent shaking of the ground sometimes causing great destruction as a result of movements within the earth crust or volcanic action.

Earthquake terminology :

1. Focus or hypocenter or origin : [2015,2016]
The place of origin of the earthquake in the interior of the earth is known as focus or hypocenter or origin or center.

2. Epicenter : [2015]
The place on the earth's surface which lies exactly above the focus of the earthquake is known as epicenter. Destruction will be maximum at this place.

3. Anticenter : [2011,2016]
The point on the earth's surface diametrically opposite to the epicenter is called the anticenter.

4. Seismic vertical:

The imaginary line joining the focus and epicenter is called seismic vertical. This represents the minimum distance which the earthquake has to travel to reach the surface of the earth.

5. Isosiesmal:

An imaginary line joining the points of same intensity of the earthquake is called isosiesmal.

6. Cosiesmal:

An imaginary line which joints the points at which the earthquake waves have arrived at the earth's surface at the same time is called a cosiesmal.

7. Siesmic waves:

The enormous energy released from the focus at the time of earthquake is transmitted in all directions in the form of waves known as siesmic waves

8. Mainshock:

The largest earthquack in a series is called mainshock.

9. Foreshock :

Foreshocks are relatively smaller earthquakes that occur before the mainshock. Not all mainshocks have the foreshocks.

10. Aftershocks :

Aftershocks are earthquakes that follow the largest shock (mainshock) of an earthquake sequence. They are smaller than the mainshock. Aftershocks can continue over the period of weeks, months or years. In general the larger the mainshock, the larger and more numerous the aftershocks.

11. Siesmology : [2013]

The scientific study of the earthquake and the internal structure of the earth is called siesmology. It includes the study of the origin, effects, geographic distribution and possible prediction of earthquake.

12. Seismometer:

A seismometer is an instrument that detects seismic waves.

13. Seismograph: [2013]

A seismograph is a machine that records ground movement from earthquake. The information recorded tell us about the strength and speed of the energy travelling from the breaking point underground.

14. Seismogram: [2004, 2013, 2015]

A seismogram is a graph output by a seismograph. It is the record of the ground motion at a measuring station as a function of time.

15. Seismic activity:

Seismic activity is defined as the types, frequency and size of earthquakes that happen over a period of time in a certain area.

16. Ground acceleration: [2011]

Ground acceleration or peak ground acceleration (PGA) is the maximum ground acceleration that occured during earthquake shaking at a location. PGA is what is experienced by a particle on the ground. Earthquake shaking generally occurs in all three directions.

17. Seismic coefficient: [2004, 2008, 2010, 2011, 2016]

Seismic coefficients are dimensionless coefficients which represents the maximum earthquake acceleration as a fraction of the acceleration due to gravity. Typical values are in the range of 0.10 to 0.30

18. Base shear force : [2011]

Base shear force is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. It depends on soil condition at the site.

Types of seismic waves : [2005,06,08,09,11,12,13]

There are mainly two types of seismic waves.

1 Body wave

2. Surface wave.

Body wave :

It spreads outward from the focus in all directions.

Body waves consist of

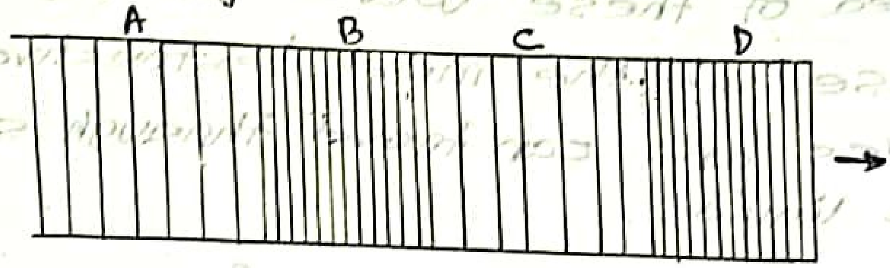
a. Primary wave (p. wave)

b. Secondary wave (s. wave)

Primary wave :

It is compressional wave that travels in the same direction the wave moves. This wave is the faster among the seismic waves and the travelling speed is 8–13 km/sec.

This is the first wave to reach any station and hence the first to be recorded. This is capable of travelling through solids, liquids and gases.



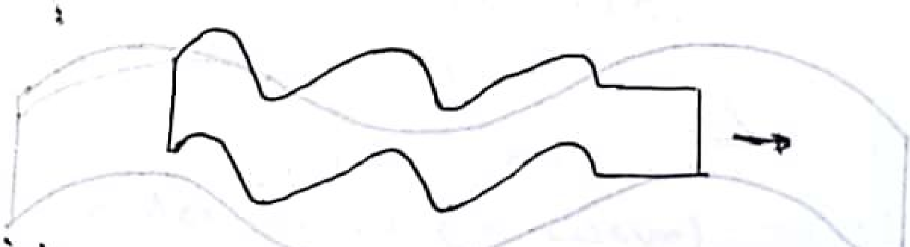
Secondary wave: It is transverse wave that travel perpendicular to the direction of wave movement. This wave is slower than primary wave and travelling speed is 5-7 km/sec. For this reason this wave always recorded after primary wave. It can pass through only solids.

Surface waves: It spread from the epicenter to the earth surface. These waves are produced when the earthquake reaches at the earth surface. These are the slowest moving waves and are the last to be recorded in the seismic station. The travelling speed of these waves are 4-5 km/sec. These are the most destructive waves and can travel through solids and liquids.

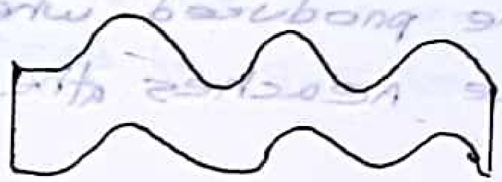
Surface waves consist of

a. Love wave (L-wave)
b. Raleigh wave

<u>Love wave:</u> Love waves that have not any vertical pattern. It just moves from side to another in a horizontal motion. It is the most destructive waves.



<u>Raleigh wave:</u> Raleigh waves are the waves that are travelling directly upwards from the solid. The wave pattern in elliptical. It is less faster and less dangerous than love wave.



Classification of earthquake:

A. Based on the depth of origin:

i. Shallow earthquake: Earthquake with a focus depth less than 60km are called shallow earthquake.

ii. Intermediate earthquake: If the depth is more than 60 km and less than 300km they are called intermediate earthquake.

iii. Deep earthquake: If the depth is more than 300 km then the earthquake is called deep earthquake.

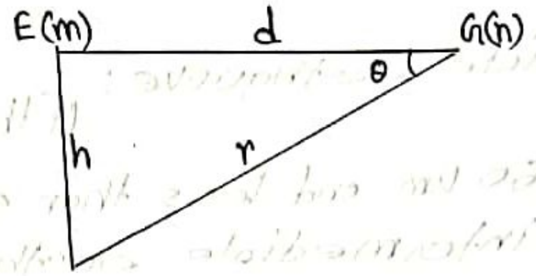
B. Based on causes of occurance:

i. Tectonic earthquakes: It is exclusively due to internal causes i.e. due to disturbances or adjustments of geological formations taking place in the earth's interior. Naturally they are less frequent, but more intensive and hence more destructive in nature.

ii. Non-tectonic earthquakes: It is due to external or surface causes. very frequent. minor intensity and not destructive in nature.

Determination of the depth of focus of a earthquake:

According to Oldham the depth of the focus can be estimated by comparing the intensities at the epicenter and at other station.



Here, $\sin^2\theta = h^2/r^2 = n/m$

and focus depth, $h = d\tan\theta$.

Where, E = epicenter

G = a station where intensity is known

m = intensity at epicenter.

n = intensity at G.

Magnitude of earthquake: Magnitude measures the energy released at the source of the earthquake. Magnitude is determined from measurements of seismographs.

Intensity of earthquake: Intensity measures the strength of shaking produced by the earthquake at a certain location. Intensity is determined from effects on people, human structures and the natural environment.

Causes of earthquake: [2008, 2011]

Due to the following causes earthquake can occur:

1. Surface causes:
   a. Landslides
   b. Large sea waves
   c. Large rock break down
   d. Great explosions.
2. Volcanic causes.
   a. Sudden explosion due to volcanic activity
   b. Movement of magma.
3. Tectonic causes:
   a. Increase of pressure inside the earth
   b. Chemical adjustment and readjustment inside the earth.

Earthquake scales:

Various scales are used to measure earthquake intensity and magnitude. Some of them are:

1. Richter scale
2. Mercally scale
3. Moment magnitude scale.

Richter scale:

In 1935 Charles Richter devised first magnitude scale for measuring earthquake size. This is commonly known as Richter Scale.

Richter used observation of earthquakes in California to determine a 'reference event'. The magnitude of an earthquake is calculated by comparing the maximum amplitude of the signal with the reference event at a specific distance. The Richter scale is logarithmic that means the amplitude of magnitude 6 earthquake is 10 times greater than the magnitude 5 earthquake. It is not commonly used anymore except for small earthquakes recorded locally.

Measuring earthquake by Richter scale: [CT-13] 2015

i. Measure the intervals between the arrival of first P-wave and S-wave in seconds.

ii. Measure the amplitude of largest S-wave.

iii. Use nomogram to estimate distance from epicenter and magnitude.

IV. Use seismograms from at least three geographic locations to locate epicenter by triangulation.

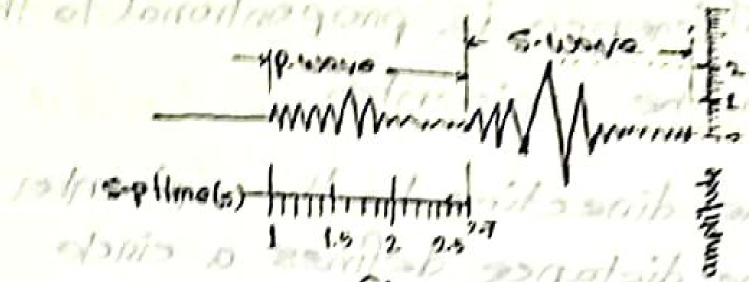


Fig: Seismogram

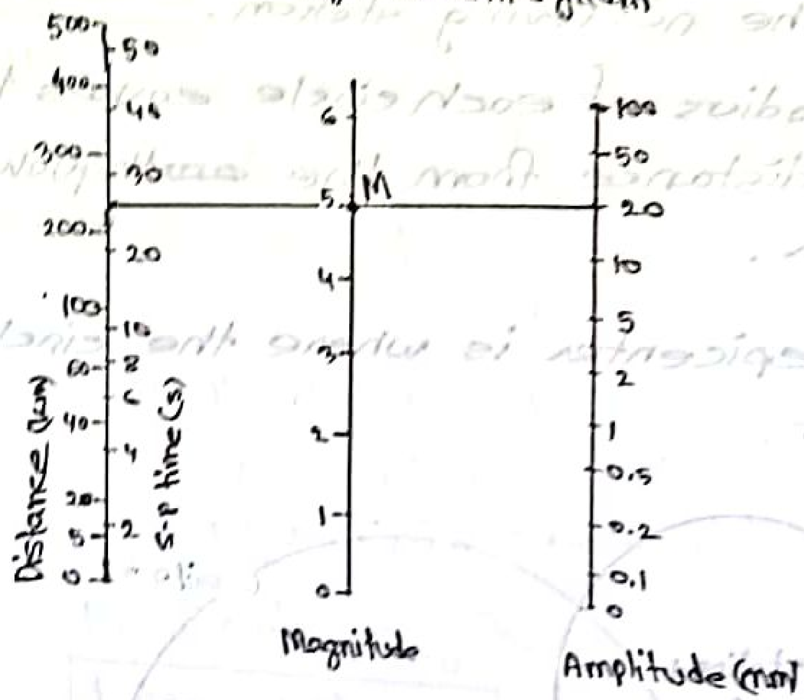


Fig: Nomogram.

<u>Location of epicenter:</u>

Seismologists can locate the epicenter of an earthquake as long as the vibrations are felt at three different seismograph stations.

1. locate at least three stations on a map that recorded the seismic waves.

II. Calculate the time difference between arrival of p-waves and arrival of s-waves from a seismogram.

III. The time difference is proportional to the distance from the epicenter.

IV. Because the direction to the epicenter is unknown, the distance defines a circle around the recieving station.

V. The radius of each circle equals that station's distance from the earthquake epicenter.

VI. The epicenter is where the circles intersect.

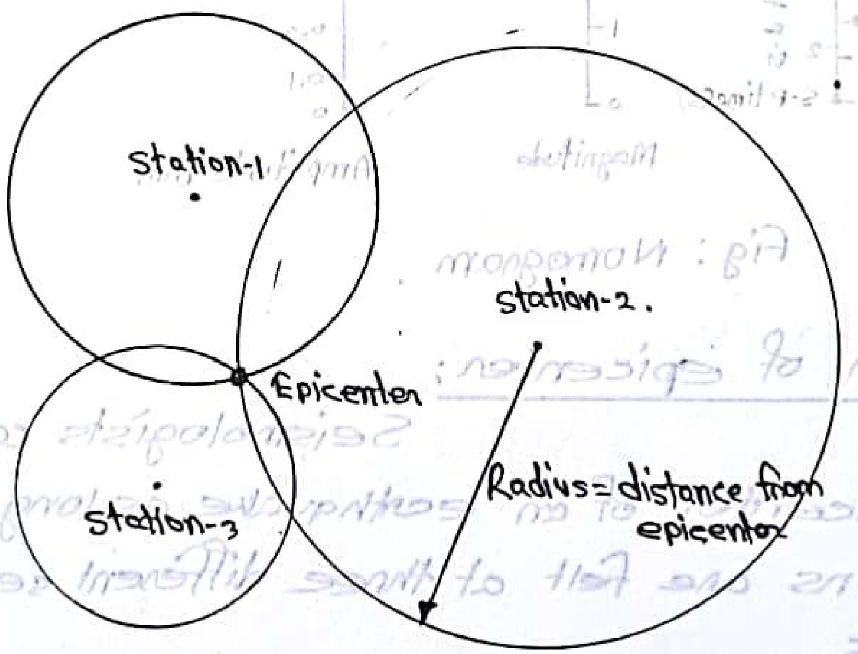


Fig: Epicenter location by using three stations.

Limitations of Richter scale:

i. The Richter scale only applied to shallow focus earthquake in Southern California. So it must be modified.

ii. Magnitude calculated from seismograms above 7 tends to be inaccurate.

Measure of size of earthquake:

A better measure of size of an earthquake is the amount of energy released by the earthquake, which is related to the Richter scale by the following equation:

$$\log_{10} E = 11.8 + 1.5M$$

where,

E = Energy released in ergs.

M = Richter magnitude.

$$\boxed{1 \text{ erg} = 10^{-7} \text{ joule}}$$

Richter scale formula:

Magnitude of an earthquake is determined from the logarithmic of amplitude of waves recorded by seismograph. The magnitude is given by

$$M_L = \log A - \log A_0$$
$$= \log(A/A_0)$$

Where, M_L = local magnitude

A = maximum traced amplitude (mm)

A_0 = 0.001 mm.

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What do you mean by earthquake size 5 and 7? [CT-13]

Here Magnitudes $M_5 = 5$ and $M_7 = 7$.

We know. $\log_{10} E = 11.8 + 1.5M$

Now $\log_{10} E_5 = 11.8 + 1.5 M_5$

$= 11.8 + 1.5 \times 5$

$= 19.3$ ------ (i)

and $\log_{10} E_7 = 11.8 + 1.5 \times 7$

$= 22.3$ ------ (ii)

Equation (ii) − (i) ⇒ $\log_{10} E_7 - \log_{10} E_5 = 22.3 - 19.3$

⇒ $\log_{10}(E_7/E_5) = 3$

⇒ $E_7/E_5 = 10^3$

⇒ $E_7 = 1000 E_5$

Therefore, energy released in earthquake size 7 is 1000 times more than in earthquake size 5.

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Richter scale related to intensity:

Magnitude	Damages
1-3	Recorded on local seismographs but generally no felt.
3-4	Often felt but no damage
5	Felt widely, slight damage near epicenter.
6	Damage to poorly constructed structures within 10 km.
7	Major earthquake, causes serious damage upto 100 km (Gujarat 2001 EQ)
8	'Great' earthquake, great destruction loss of life over several 100 km
9	Rare great earthquake, major damage over a large region over 1000 km

Mercalli scale:

It is a seismic intensity scale used to measure the intensity of an earthquake based on observed effect. Mercalli scale qualifies the effect of an earthquake on earth's surface, on human, object of nature and man made structures on a scale from I to XII.

Limitations of Mercalli's scale:

The intensity of same earthquake is different measured from different places. As the visual destruction is not same in all the places due to an earthquake.

Modified Mercalli scale:

It deals with the manner in which the earthquake is felt by people. The higher number of scale is based on observed structural damages.

Modified Mercalli intensity scale:

Scale	Damages
I	Not felt
II weak	Felt only by persons at rest.
III-IV weak-light	Felt by persons indoor only
V-VI moderate-strong	Felt by all, some damages to plaster, chimneys
VII very strong	People run outdoors, damage to poorly structures
VIII severe	Well built structure slightly damaged, poorly built structures suffer major damage
IX violent	Buildings shifted off foundations
X Extreme	Some well built structures destroyed.
XI Extreme	Few masonry structures remain standing, bridges destroyed.
XII Extreme	Damage total, waves seen on ground, objects thrown into air.

Moment magnitude scale:

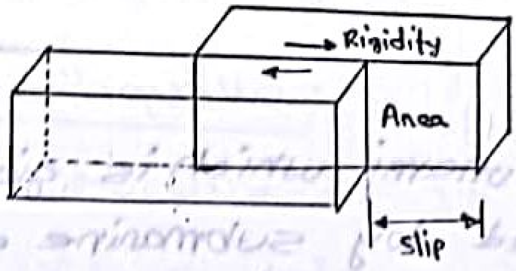
Moment magnitude scale is a more accurate measure of the earthquake size. Moment magnitude (M_w) is based on the physical properties of the earthquake derived from an analysis of all the waveforms recorded from the shaking. First the seismic moment is computed and then it is converted to a magnitude designed to be roughly equal to the Richter scale in the magnitude range where they overlap.

Seismic moment, M_0 = rigidity × area × slip.

Where, rigidity = the strength of the rock along the fault.

Area = Area of the fault that slipped

Slip = distance the fault moved.



Moment magnitude, $M_w = \frac{2}{3} M_0 - 10.7$.

Effects of earthquake: [CT.EC]

There are various effects of earthquake.

1. Ground shaking:
Due to the energy released at the time of earthquake, the ground shakes and the construction on the ground collapse.

2. Liquefaction:
Due to the earthquake energy the water enters into the soil grains and saturate it. At this time the soils behave like a viscous fluid with no shearing and bearing capacity. As a result structures on the soil collapse, settle down and tilt.

3. Land slide:
The shearing resistance of soil will reduce due to the earthquake. Because of this the soil slope fails and flow.

4. Tsunami: [2004]
Tsunami which is giant tital waves caused by submarine earthquake. The waves can grow up to 65m and destroy all the structures.

5. Fire hazard:
At the time of earthquake fire can result from broken gas and electric wire.

What precautions should be taken before during and after earthquake? [EC]

The precautions are taken to mitigate the effects are as follows:

Before earthquake:

i. All important things are kept in safe place.
ii. All people should go to other safe place.
iii. Tall heavy furniture which could fall, fix it to the wall.
iv. Hot water heaters need to be anchored to the wall.
v. Place large and heavy objects on lower shelves.
vi. Repair any deep cracks in ceilling and foundation.

During earthquake:

i. It should be possible to go open field.
ii. Do not use elevator and don't try to run.
iii. Cover head and neck with arms.
iv. Do not get in a doorway as it does not provide protection from falling objects.

v. Do not re-enter and stay away from the damaged home.

vi. Should hold on to any shelter until the shaking stop.

After earthquake:

i. Use flashlight instead of candle or lantern to avoid fire hazard.

ii. Stay out of damaged building

iii. Check for electric damage, gas leakage and other damages.

iv. Keep abreast of the latest emergency news if possible.

v. Help to trapped and injured people and give first aid if possible.

vi. Return home only when the authorities declare it safe.

Factors should be considered in designing and construction of seismic resistant structures : [2009, 2010, 2013, 2015

The following factors should be considered in designing and construction of seismic resistant structures :

i. Structures should not be brittle.

ii. Resisting elements must be provided.

iii. All elements should be tied together.

iv. The structures must be well-connected to the good foundation and earth.

v. Good quality material should be used throughout the construction.

vi. Foundation depth should be uniform.

vii. Doors and windows should be in vertical rows.

viii. Height should be kept uniform.

ix. The walls should be continuous with few doors and windows.

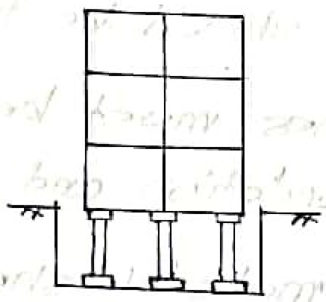
x. Cantilever portion of the building should be avoided.

Earthquake resisting techniques: [2006, 2007, 2016

1. Create a flexible foundation:

i. The building is constructed on top of flexible pads that isolate the foundation from the ground.

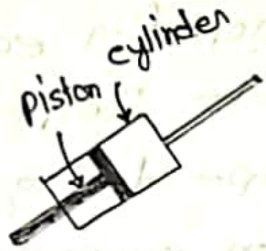
ii. When an earthquake hits only the base moves while the structure remains steady.



2. Counter forces with damping:

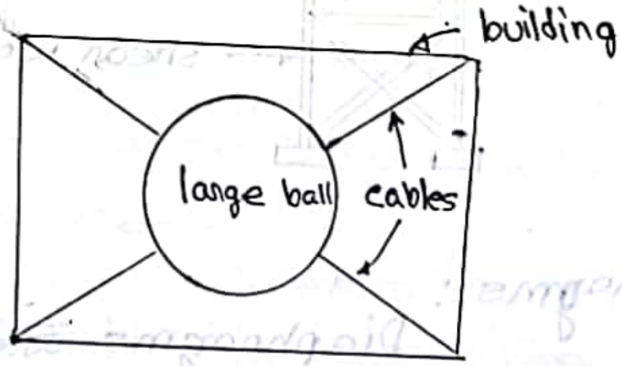
Magnitude of shockwaves due to earthquake can be reduced by using ① vibrational control device and ⑪ pendulum dampers.

i. vibrational control device: place dampers at each level of a building between a column and beam. Each damper consists of piston head inside a cylinder filled with silicon oil. When an earthquake occurs building transfer the vibration energy into the pistons pushes against the oil. The energy is transformed into heat, dissipating the force of the vibrations.



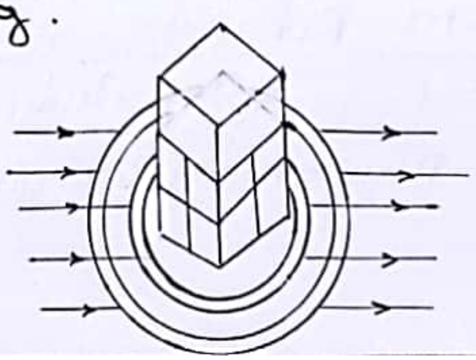
11. Pendulum power:

A large ball with steel cables with a system of hydraulics at the top of the building move opposite the earthquake movements to dampen or dissipate the energy.

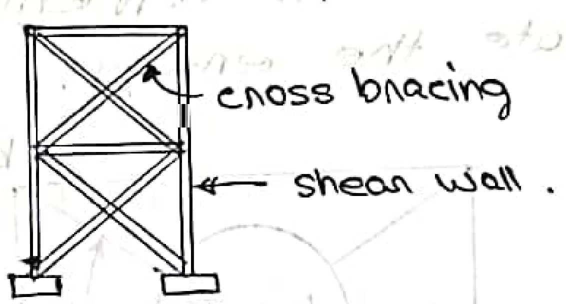


3. Sheild buildings from vibrations:

Concrete and plastic rings are placed at least 3 ft. beneath the foundation of the building to channel shockwaves around the building.



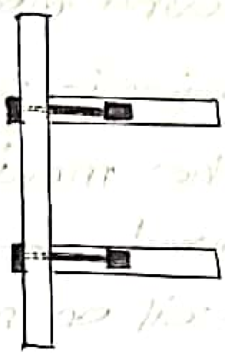
4. Shear walls and bracing: Shear walls are a useful building technology that helps to transfer earthquave forces. Made of panels, these walls help a building keep its shape during movements. Shear walls are often supported by diagonal cross broces. These steel beams have the ability to support compression and tension which helps counteract the pressure and push forces back to the foundation.



5. Diaphragms: Diaphragms are the center part of a building structure. Consisting of the floors of the building, the roof, and the decks placed over them, diagnagms help remove tension from the floor and push force to the vertical structures of the building.

6. Moment resisting frames:

Moment resisting frames provide more flexibility in a building design. This structure is placed among the joints of the building and allows for the columns and beams to bend while the joints remain rigid.



7. Earthquake resisting materials:

Some earthquake resisting materials: There are

i. Structural steel:

Various shapes allow material to bend without breaking.

ii. Wood:

Lightweight material with good weight to strength ratio.

Seismic zones in Bangladesh: [2013]

The intent of the seismic zoning map is to give an indication of the maximum considered earthquake (MCE) motion at different parts of the country. The country has been divided into four seismic zones with different levels of ground motion.

Each zone has a seismic zone coefficient (Z) which represents the maximum considered peak ground acceleration (PGA) on very stiff soil or rock in units of g.

Description of seismic zones:

Seismic Zone	Location	Seismic intensity	Z
1	Southwestern part including Barisal, Khulna, Jessore, Rajshahi	Low	0.12
2	Lower central and Northwestern part including Noakhali, Dhaka, Pabna, Dinajpur as well as Southwestern corner including Sundarbans.	Moderate	0.20
3	Upper central and Northwestern part including Brahmanbaria Sirajganj, Rangpur	Severe	0.28
4	Northwestern part including Sylhet, Mymensing, Kurigram	Very severe	0.36

Fig: Seismic zoning map of Bangladesh.

Explain the elastic rebound theory for earthquake. [EC]

The elastic rebound theory is the scientific scientific explanation for the cause of earthquakes. Here are the steps in the theory:

1. Locked fault position: Rocks on plates along a fault line are pressed tightly together. Friction prevents these rocks from sliding past each other. therefore the fault is in a locked position.

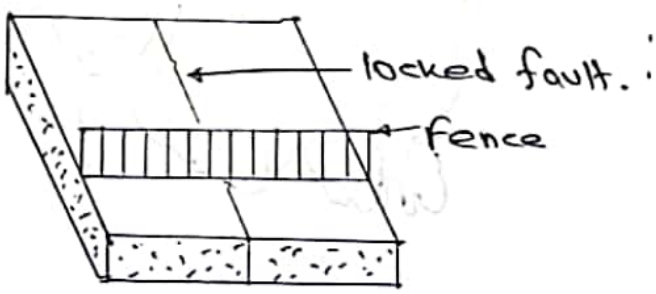
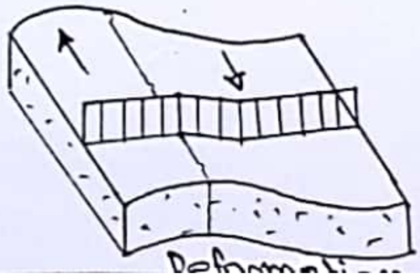
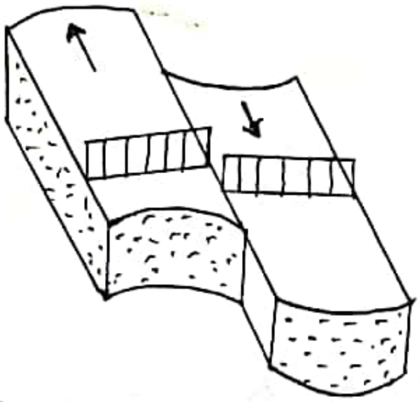


Fig: Original position.

2. Deformation: Stress builds on the fault as the plates push in opposite directions. This causes the crust to become deformed around the fault.

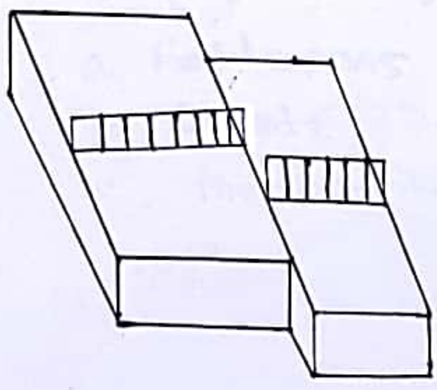


3. Plate slippage (earthquake): When the stress at the fault line becomes strong enough to overcome the friction holding the plates together, the plates fracture and suddenly grind or slip past each other. The energy released by this sudden grinding is felt as an earthquake.



Rupture and release of energy.

4. Plate rebound: During the earthquake the plates or rock snap back or rebound to their original shape. However these plates moved and are in a new location.



MINERALOGY

Mineralogy : [2015]

It is a subject of geology specializing in the scientific study of chemistry, crystal structure and physical properties of minerals.

Mineral :

A mineral is a naturally occuring substance representable by a chemical formula and it is usually solid and inorganic having a crystal structure and physical properties.

Common silicate minerals :

1. Ferromagnesian (dark) silicate (containing ions of Fe and/or Mg) :
   a. Olivine
   b. Pyroxenes
   c. Amphiboles
   d. Biotite etc.

2. Non-ferromagnesian silicate (without Fe or Mg but with Ca, Na and K) (light color) :
   a. Feldspars
   b. Quartz
   c. Muscovite etc.

Clay minerals:

i. Generally fine grained, has sheet structure

ii. Mostly as weathering products of other silicate minerals.

iii. constituting a major part of the soil, thus important for agriculture and engineering.

iv. A most clay mineral is kaolinite (used to make chinawars).

v. Some clay minerals (smectite, vermiculite absorb large amount of water. Expansive clays are a major geologic hazard. They are landslide prone and disrupt foundations.

Common non-silicate minerals:

1. Fluorite : used as a toothpaste additive.
2. Calcite (calcium carbonate): Limestone is made of calcite.
3. Dolomite (calcium.magnesium carbonate)
4. Gypsum (calcium sulfate)
5. Galena (lead sulfide)
6. Pyrite (iron sulfide) → fool's gold.
7. Halite (sodium chloride): Table salt

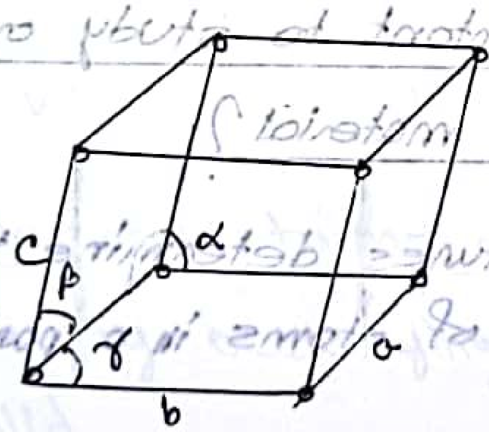
Crystal :

A crystal or crystalline solid is a solid material whose contiluents such as atoms, molecules or ions are arranged in a highly ordered microscopic structure forming a crystal lattice that extends in all directions.

In a crystal structure the atoms, molecules or ions pack together in an ordered arrangement. Crystal structure controls the shape of crystal faces.

Types of crystal structure :

There are seven main structures of crystals. depending on the shape of the crystal.



1. Triclinic : $a \neq b \neq c$ and $\alpha \neq \beta \neq \gamma$
2. Monoclinic : $\neq b \neq c$ and $\alpha = \gamma = 90°$
   $\beta \neq 90°$

3. Orthorhombic :

$$a \neq b \neq c$$
$$\alpha = \beta = \gamma = 90^\circ$$

4. Tetragonal :

$$a = b \neq c$$
$$\alpha = \beta = \gamma = 90^\circ$$

5. Cubic :

$$a = b = c$$
$$\alpha = \beta = \gamma = 90^\circ$$

6. Hexagonal

$$a = b \neq c$$
$$\alpha = \beta = 90^\circ \text{ and } \gamma = 120^\circ$$

7. Rhombohedral :

$$a = b = c$$
$$\alpha = \beta = \gamma \neq 90^\circ$$

Why is it important to study crystal structure of a material?

I. Crystal structures determine the arrangement of atoms in a particular material.

II. It also signifies the bond lengths and the lattice parameter of a particular material.

III. The atomic arrangement is

responsible for the strength and ductility of a material.

iv. It also determines the strength of a material.

Chemical composition of mineral: [EC]

1. Negetively charged ions:
   a. O^{2-}
   b. F
   c. S^{2-}
   d. Cl^{-}
2. Positively charged ions:
   a. Na^{+}
   b. Ca^{+}
   c. Al^{3+}
   d. Si^{4+}
   e. K^{+}
   f. Fe^{2+}
   g. Fe^{3+}
   h. C^{4+}
   i. Mg^{2+}

Requirements to be a mineral:

i. Naturally occurrying
ii. Solid
iii. Inorganic
iv. Crystalline
v. Specific chemical composition

Mineral groups:

Group	Examples
Oxides	Hematite (Fe_2O_3). corundum (Al_2O_3) Water ice (H_2O)
Sulphides	Galena (PbS). Pyrite (FeS_2); calcopyrite ($CuFeS_2$)
Sulphates	Gypsum ($CaSO_4 \cdot H_2O$) Barite ($BaSO_4$)
Halides	Fluorite (CaF_2) Halite ($NaCl$)
Carbonates	calcite ($CaCO_3$) dolomite [$(CaMg)CO_3$]
Phosphates	Apatite [$Ca_5(PO_4)_3(OH)$]. Turquoise
Silicates	Quartz (SiO_2). Feldspar ($NaAlSi_3O_8$) Olivine [$(Mg.Fe)_2SiO_4$]
Native minerals	Gold (Au), Diamond (C), Graphite (C), sulpher (S). copper (Cu).

Common rock forming minerals: [2004, 2015] [CT-13]

1. Apatite	12. Ilmenite
2. Augite	13. Magnetite
3. Biotite — 7.8	14. Muscovite
4. calcite	15. Olivine
5. chloride	16. Orthoclase
6. Fluorite	17. Plagioclase
7. corundum	18. Pyrite
8. Diamond	19. Quartz — 12
9. Garnet	20. Talc
10. Gypsum	21. Topaz.
11. Hornblende	22. feldspar.

Calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) [Carbonate minerals]:

1. Different reaction to acid
11. Commonly used for building stones, concrete aggregate, lime and portland cement.

Limonite ($FeO.H_2O$) [Oxide mineral

1. Brown streak
11. May be in gravel
111. Poor for concrete because of staining and popouts after cycles of freezing and thawing.

Pyrite (FeS_2) (sulfide minerals):

1. Brassy color
ii. Metallic lustre
iii. Cubic crystal
iv. A nuisance for concrete before of staining from oxidation.

Gypsum ($CaSO_4.2H_2O$) (sulfate minerals)

1. Hardness 2
ii. White
iii. Soluble in ground water.

Anhydrite ($CaSO_4$) (sulfate minerals):

1. Lack of effervescence in acid.
ii. Swelling when wet and converting to gypsum
iii. Disastrous when presence in foundation or tunnel.

Apatite

1. chemical composition: $Ca_5(PO_4)_3(OH, F, Cl)$
ii. Hardness 5
iii. Specific gravity 3.1-3.2
iv. Transparency: Transparent to translucen

v. Color: Typically green but also yellow, blue, reddish, brown and purple.

vi. White streak.

vii. Lustre: vitreous to greasy

viii. Cleavage: poor / concoidal.

ix. Prismitic in crystal habit.

<u>Biotite:</u>

i. Chemical composition: $K(Fe,Mg)_3AlSi_3O_{10}(F,OH)_2$

ii. Hardness: 2.5-3

iii. Specific gravity: 2.9-3.4

iv. Transparency: Transparent to translucent.

v. Brown to black color.

vi. Streak: very pale brown.

vii. Lustre: vitreous to pearly

viii. Cleavage: perfect in one direction.

ix. Crystal habit: Tabular/ granular.

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physical properties of minerals:

I. Color

II. Lusture

III. streak

IV. Hardness

V. crystal habit

VI. cleavage and fracture

VII. specific gravity

VIII. Transparency

Color:

Various in many minerals e.g. quartz. Some minerals come in just one color, other are many colors or many varieties.

Lusture:

The quantity and intensity of light reflected from the surface of a minerals. This property must be observed in hand first and can not be demonstrated in a photograph.

Streak: [2015] [CT-13]

Streak is the color of a crushed minerals powder. The color of a minerals powder may differ from the actual color of the mineral.

Hardness: [2015]

Hardness is a measure of the resistance to localized plastic deformation on scratching by using mechanical indentation. A measure of the ease with which a smooth surface of a mineral can be scratched or of its resistance to abrasion.

Soft mineral is easily scratched than hard minerals.

Talc is softest mineral, diamond is hardest.

Crystal habit:

Crystal habit refers to the overall shape of the mineral.

Types of crystal habit:

1. Equant: Three dimensions of the mineral have about the same length like a cube.

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2. Elongate: One direction is long but the other two dimensions are short like a pencil.

3. Platy: One dimension is short but the other two dimensions are long like a sheet of paper.

Cleavage: [2015] [CT-13] Tendency of mineral to break along flat surfaces due to weak bonding is known as cleavage. Flat surfaces is known as cleavage faces.

Fracture: [CT-13]

Minerals that break in irregular, jagged or splintered edges are said to have fracture.

The way a mineral breaks other than along a cleavage face is called fracture.

Specific gravity:

A mineral's specific gravity is the ratio of its mass to the mass of an equal volume of water.

Transparency:

Transparency refers to the degree to which light can pass through a mineral.

a. Opaque: If no light can pass through the mineral then it is known as opaque.

b. Transculent: [2015, CT-13] If light can pass through the mineral but diffused so that image can not be seen clearly then it is known as transculent.

c. Transparent: If light can pass through the mineral and image can seen clearly then it is known as transparent.

conchoidal: [CT-13]

Tendency of mineral to break along smoothy curving fracture surface due to weak bonding is known as conchoidal fracture.

Is salt a mineral?

Salt is a mineral consisting primarily of sodium chloride (NaCl), a chemical compound belonging to the larger class of salts. Salts is in natural form as a crystalline mineral is known as rock salt.

Is paper a mineral?

It is not a mineral because

1. Paper is not posses a crystalline structure
ii. It is an organic compound.
iii. It does not have a definite chemical composition.

Is coal a mineral?

Coal is not a mineral because it comes from organic materials. It is formed from the remains of dead plants and animals, that have no definite chemical composition. So it can not be considered as mineral. Coal is organic sedimentary rock.

What is Moh's scale of hardness: [CT-13]

The Moh's scale of mineral hardness is a qualitative ordinal scale characterizing scratch resistance of various minerals through the ability of harder material to scratch softer material.

In 1822 An Austrian mineralogist named Friedrich Moh devised a scale based on on mineral's ability to scratch another. He placed 10 minerals in order from softest to hardest giving a relative hardness value of 1 to the softest mineral and 10 to the hardest mineral. Each mineral in the scale scratches the one below it but not the one above it.

Minerals	Hardness
Diamond	10
Corundum	9
Topaz	8
Quartz	7
Orthoclase	6
Apatite	5
Fluorite	3
Calcite	4
Gypsum	2
Talc	1

* Finger nail - 2.5
* steel file - 6.5
* knife blade - 5
* Window glass - 5.5

* Texus Girls Can Flirt And For Quarters They Can Dance.

How can determine unknown hardness of a mineral? [2007, 2009, 2010, 2013]

How can Mohs scale be used in determining the unknown hardness of a mineral? [CT-13, 2011]

i. Select a fresh clean surface on the specimen to be tested.

ii. Hold the specimen firmly and attempt to scratch it with the point of an object of known hardness.

iii. If the surface of the mineral is scratched then it is softer than the mineral used to scratch.

iv. If the surface of the unknown mineral is not scratched then it is harder than the mineral used to scratch.

v. Repeat this process to get the actual hardness of the testing mineral.

vi. By this way the unknown hardness of a mineral can be obtained.

Steps and tests to completely describe and identify the unknown minerals./Identifying properties of minerals. [2015]

There are seven ways to identify the unknown minerals. They are -

1. Color:

a. The same mineral can come in a variety of colors.

b. For example in its purest state quartz is clear. But some types and varieties can contain impurities and can be a variety of colors.

c. Other factors can change the appearance of minerals.

d. The mineral pyrite often called fool's gold normally has golden brown color. But if it is exposed to air and water for a long period of time it can turn brown or black.

e. Color is usually not the best way to identify a mineral.

2. Luster:

a. The way a surface reflects light is called luster.

b. Minerals can have a metallic, submetallic or non metallic luster.

c. If a mineral is shiny it has a metallic luster.

d. If a mineral is dull its luster is either sub metallic or nonmetallic.

3. Streak:

a. The color of a mineral in powdered form is called the mineral's streak.

b. A mineral's streak can be found by rubbing the mineral against a piece of unglazed porcelain called a streak plate.

c. The mark left on the plate is the streak.

d. The streak is a thin layer of powdered mineral.

e. Streak is not affected by air or water.

f. Using streak is more reliable than using color in identifying a mineral.

4. Cleavage:

cleavage is the splitting of a mineral along smooth, flat surfaces.

5. Fracture:

Fracture is a manner in which a mineral breaks along either curved or irregular surfaces.

6. Hardness:

a. A mineral's resistance to being scratched is called hardness.

b. To determine the hardness of minerals, Scientists use Mohs hardness scale.

c. The greater a mineral's resistance to being scratched is the higher the mineral's rating.

7. Density and specific gravity:

a. Density is the ratio of mass of substance to the volume of the substance.

b. Specific gravity of a mineral is a ratio of the weight of the mineral to the weight of an equal amount of water at 4°c.

c. very good identification tool.

Mineraloids:

A mineraloid is a naturally occurring mineral-like substance that does not demonstrate crystallinity. Its chemical compositions vary when compared to specific minerals that have specific acceptable ranges.

Examples: Opal, obsidian, Pearl, Tektite, water, amber.

Differences between minerals and mineraloids:

Mineral	Mineraloid
Mineral is solid in natural state	May not solid in natural state. Example: Water
It is crystalline in form.	It is amorphous in form
It has an ordered atomic structure.	It has an unorganized atomic structure.

Uses of minerals:

Minerals occupy a major part of the earth's crust. The importance of minerals lies in the fact that whatever we use or see in our daily life, be it a toothpaste or a toothpaste factory everything and anything is made from minerals. These are not just used in the making of material things but are also present in the food we eat

a. Uses of metallic minerals:

Since metallic minerals are sources of metals, they are good conductors of heat and electricity. The following are few uses of some important metallic minerals:-

i. Alluminium:

Alluminium is the mots abundant metallic mineral in the earth's crust. It finds application in a number of industries including:

- Automobile industry
- Building industry
- Electrical industry
- Manufacture of can, bottles etc.

ii. Copper :

It is another important metallic mineral which has a wide range of uses.

- It is used in making machine parts, electronic components and electric wires etc.
- Coins and Jewellery are also made using copper.
- Plant diseases can also be treated using copper compounds.

iii. Gold :

Gold is a metallic mineral which is very lustrous. It is primarily used in making Jewellery. Being an excellent conductor of electricity it also be used in electronic industry.

b. Uses of minerals in the body :

Minerals play a vital role in the growth and development of the human body. Following are few minerals required by the human body and their uses.

i. Calcium :

It is the most abundant mineral found in the human body and is required for healthy bones and teeth. It also helps in regulating blood pressure and immune system and fluid balance within cells.

ii. Potassium & sodium:

They play a vital role in carrying out electrical and cellular functions in the human body. These are used for nerve transmission and muscle contraction. High intake of sodium causes hypertension.

iii. Sulpher:

It is an important part of protein. It is also necessary for insulin production.

iii. Phosphorus:

It is required for healthy bones. The skeleton consists of 85% of body phosphorus.

iv. Magnesium:

A major portion of magnesium is present in bones. It is important in carry out neuromuscular transmissions and various functions of enzyme systems.

c. Economic uses of minerals:

i. Apart from non-metallic minerals precious metals like gold, silver and platinum also have great economic importance.

ii. Energy minerals like coal, petroleum, natural gas are the basic fuels and are used in thermal power generation, automobile engins, cosmetic industries, manufacture of synthetic rubber and much more.

ROCKS

Rock: [2004]

A rock is a solid, inorganic and naturally occurring aggregate of one or more minerals without a particular atomic structures or chemical composition.

Examples: Granite, limestone, marble, pumice, obsidian, sandstone, shale and slate.

Classification of rock:

There are three major rock types:

1. Igneous rock.
2. Sedimentary rock.
3. Metamorphic rock.

Igneous rock: [CT-Influence 14]

Igneous rocks are formed by the cooling and solidification of molten magma or lava near at or below the earth's surface. It is also known as magmatic rock or primary rock.

Examples: Granite, Pumice, Scoria

Magma:

Magma is the molten or semi-molten natural material below or within the earth's crust from which lava and all igneous rocks are formed on cooling.

Lava:

Magma at the surface of the earth is called lava.

Classification of igneous rock based on depth of origin / textural classification: [2001][CT-13]

1. Plutonic rocks:

The igneous rocks which have formed under high pressure at great depths in the earth's crust are called plutonic rocks. These rocks are always coarse grained.

plutonic rocks are formed:

i. under great pressure

ii. At high temperature and

iii. In the presence of huge quantities of volatiles.

Example: i. Granite

ii. Syenite

iii. Diorites

iv. Gabbros

v. Peridotities.

2. Hypabyssal rock:

The igneous rocks which have formed at shallow depths are called hypabyssal rocks. They are neither coarse grained nor fine grained but medium grained.

This rock is formed under moderate temperature and pressure.

Example: Dolerite.

3. Volcanic rocks:

The igneous rocks which have formed at the surface are called volcanic rocks. This rock is always fine grained.

The physical conditions that prevail are:

i. Solidification under atmospheric pressure.

ii. The underlysing surface rocks are relatively cold.

iii. Overlying atmospheric gases circulate continuously.

Example: i. Basalts.

ii. Rhyolites

iii. Andesites

Intrusive igneous rock: [2006, 2009] Igneous rocks are called intrusive when the cool and solidify beneath the surface. Intrusive rocks form plutons and so are also called plutonic rocks. A pluton is an igneous intrusive rock body that has cooled in the crust.
Slow cooling of magma allows time for large crystals to form, so intrusive igneous rocks have visible crystals.

Extrusive igneous rock: Ingeous rocks are called extrusive when the cool and solidify above the surface. These rocks usually form from a volcano so they are also called volcanic rocks.
Extrusive igneous rocks cool much more rapidly than intrusive rocks. There is little time for crystals to form so extrusive igneous rocks have tiny crystals.

Formation of igneous rocks:

At a certain depth (estimated to be 30 to 35 km or so) from the earth's surface the temperature will become so high that all the rocks will melt and will exist in a molten state called magma. When this hot molten magma erupts out on the earth's surface due to volcanic activities then it is called lava.

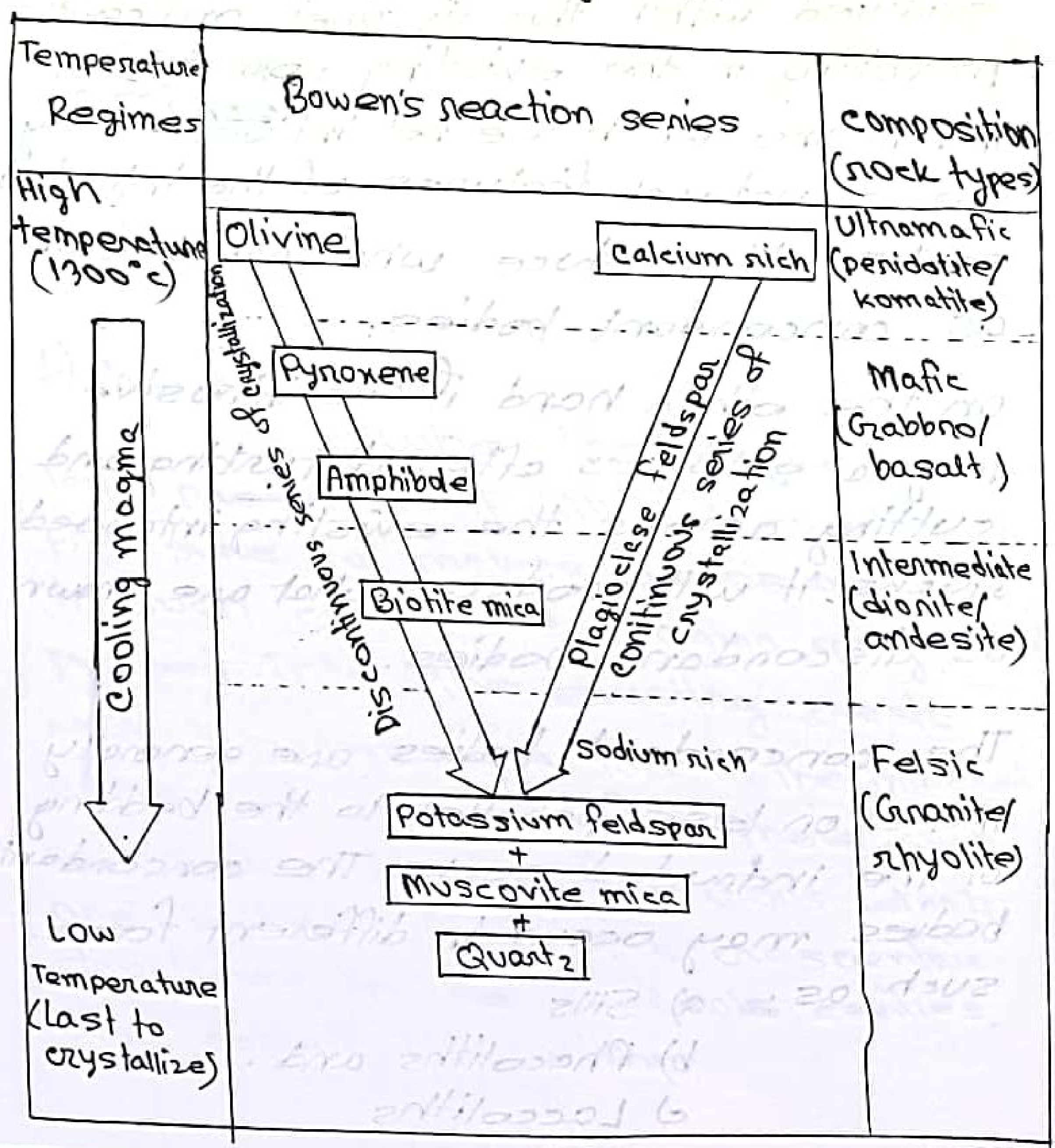
Igneous rocks are formed through the cooling and solidification of magma or lava. As hot molten rock rises to the surface it undergoes changes in temperature and pressure that cause it to cool, solidify and crystalize. Majority of igneous rocks which are formed beneath the surface of the earth's crust. However some are also formed on the surface as a result of volcanic activity.

Crystallization of magma / Bowen's reaction series for magma solidification.

The minerals that move up igneous rocks crystallize at a range of different temperatures. This explains why a cooling magma can have some crystals within it and yet remain predominantly liquid. The sequence in which minerals crystallize from a magma is known as the Bowen's reaction series.

Of the common silicate minerals, olivine normally crystallizes first at between 1200°c to 1300°c. As the temperature drops and assuming that some silica remains in the magma, the olivine crystals react with some of the silica in the magma to form pyroxene. As long as there is silica remaining and the rate of cooling is slow, this process continues down the discontinuous branch: olivine to pyroxene, pyroxene to amphibole, and amphibole to biotite.

At about the point where pyroxene begins to crystallize, plagioclase feldspar also begins to crystallize. At that temperature, the plagioclase is calcium-rich (anorthite). As the temperature drops and providing that there is sodium left in the magma, the plagioclase that forms is a more sodium-rich variety.



Forms of intrusive rocks :

The hot molten magma during its efforts to come up to the surface sometimes gets successful in melting and distributing the existing adjoining rocks and sometimes it may fail to do so. In the letter case when the magma is unable to disturb and cut across the existing intruded rocks, it may get cooled and solidified within the fissures and cavities prevailing in the existing rocks. Such intrusions which are not influenced by the structural features of the intruded rocks will produce what are known as concordant bodies.

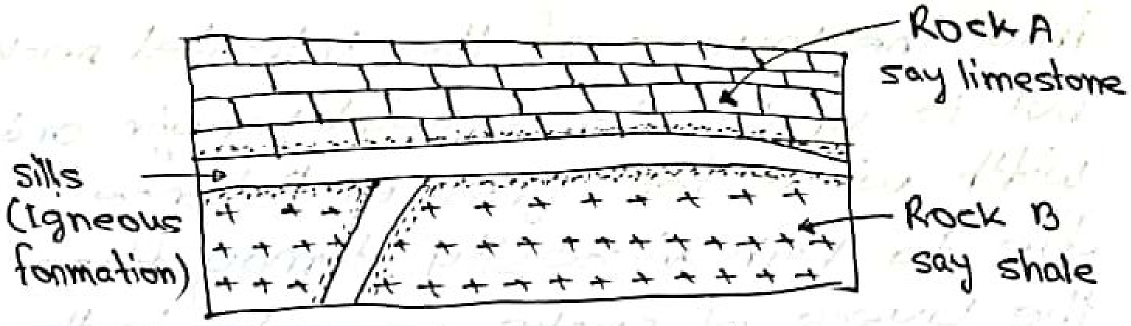
On the other hand if the intrusive magma solidifies after disturbing and cutting across the existing intruded rocks, it will produce what are known as discordant bodies.

The concordant bodies are generally more or less parallel to the bedding of the intruded rocks. The concordant bodies may occur in different forms such as :

a) Sills
b) Phacoliths and
c) Laccoliths

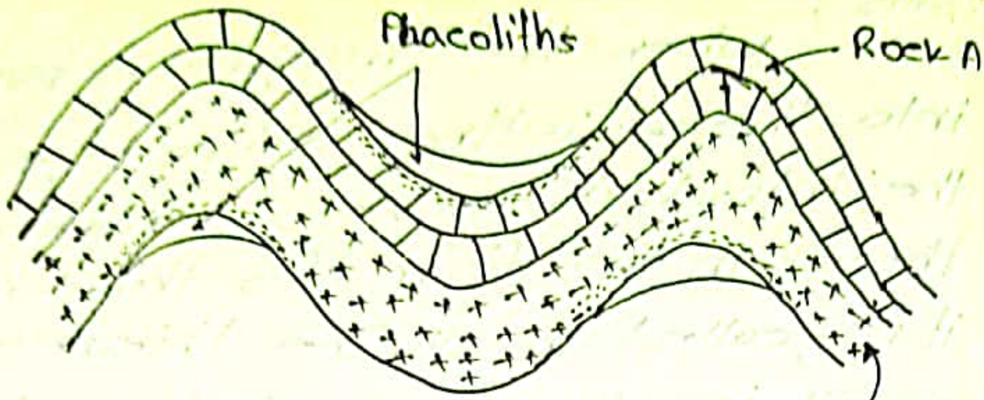
a) Sills :

When the magma is pushed into the existing bedding layers of the intruded rocks and solidifies there, in the form of a thin sheet, it is called a sill. The thickness of a sill is always much less than its width and length that generally tapers out at the ends.



b) Phacoliths :

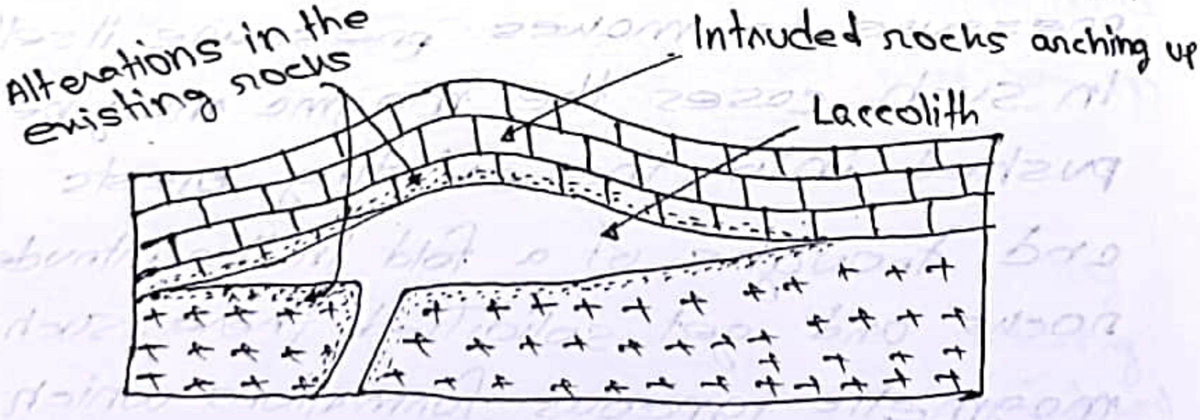
When the magma is under low pressure it will not exert much pressure to makes pressure itself. In such cases the magma may be pushed into the existing crests and troughs of a fold in the intruded rocks and get solidified there. Such magmetic igneous formations which are in the form of a crescentric structures in the available cavities are called phacoliths.



b) Phacoliths

c) Laccoliths :

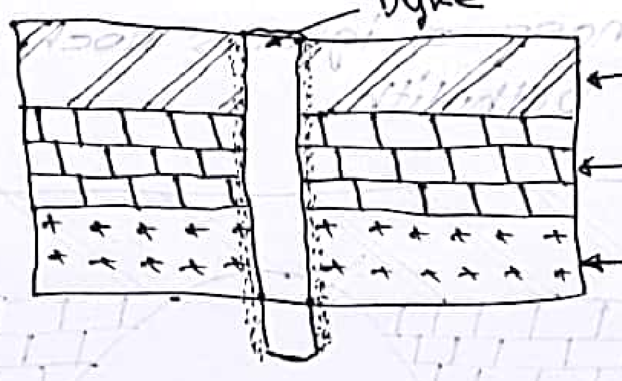
when the magma injects into the layers of the intruded rocks but is unable to spread length and width wise for greater distances due to high viscosity. it may force the layers of rocks upwards. in the form of a dome or an arch. The magma confining and solidifying in such bun-shaped masses will produce igneous rocks. known as laccoliths.



The discondant intruded bodies generally cut across these older existing rocks. The discondant bodies may occur as: a) Dykes
b) Volcanic rocks
c) Batholiths.

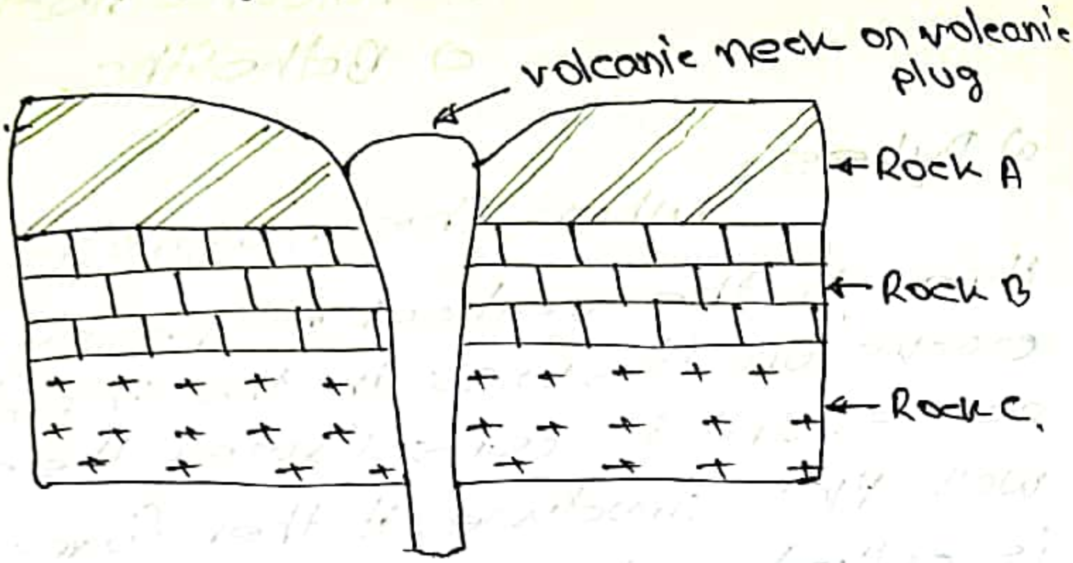
a) Dykes:

When the magma is forced through the vertical or nearly vertical cracks or fissures in the intruded rocks and is consolidated there as a wall like structure. it then forms, what is called a dyke. Dykes show a great variation in their thickness, length and height depending upon the energy and nature of the magma and the type of the intruded rocks.



b) Volcanic necks:

When the magma is forced into the holes of inactive volcanoes and gets solidified there in the form of more or less a circular thick pipe, then it is called a volcanic neck or volcanic plug. The volcanic necks generally show inward dipping contacts with the country rocks.



c) Batholiths : when the magma moving under high pressure fills a large space in the pre-existing intruded rocks by melting them or keeping them aside, or by any other means; thus forming a huge mass of igneous rock then it is called a batholith.

Different textures in ingeous rocks: [CT-Influence 14]

Igneous textures include the rock textures occurying in igneous rocks. Igneous textures are used by geologists in determining the mode of origin igneous rocks and are used in rock classification. There are six main types of textures:

1. Phanenitic:

I. Phenenitic textures are typical of intrusive igneous rocks, these rocks crystalized slowly below earth's surface.

II. As magma cools slowly the minerals have time to grow and form large crystals.

III. The minerals are sufficiently large to see each individual crystal with the naked eye.

IV. Examples: Gabbro, Dionite, Granite.

2. Aphanitic:

I. Aphanitic rocks in contrast to phanenitic rocks.

II. Typically forms form lava which crystalize rapidly on on near earth surface.

III. Extrusive rocks cool slowly so the minerals donot have time to form large crystals.

IV. The individual crystals are invisible in naked eye.

V. Examples: Basalt, Andesite and rhyolite.

3. Porphyritic:

I. Porphyritic textures develop when conditions during cooling of a magma change relatively quickly.

II. The earlier formed minerals will have formed slowly and remain as large crystals.

III. Sudden cooling causes the rapid crystalization of the remainder of the melt into a fined grained matrix(aphanitic)

IV. It also occurs when magma crystalizes below a volcano but is erupted before completing crystalization thus forcing the remaining lava to crystalize more rapidly with much smaller crystals.

4. Glassy/vitreous:

I. Glassy or vitreous textures occur during some volcanic eruptions when the lava is quenched so rapidly that crystalization can not occur.

II. The result is a natural amorphous glass with few or no crystals.

III. Examples: Obsidian and pumice.

5. Pyroclastic :

i. This texture occurs when explosive eruptions blast the lava into the air resulting in fragmental.

ii. Typically glassy material which fall as volcanic ash, lapilli and volcanic bombs.

6. Pegmatitic :

1. This texture occurs during magma cooling when some minerals may grow so large that they become massive.

ii. This is typical of pegmatities.

Structures of igneous rocks :

The characteristic features that give conspicuous (उभरा) appearances to a rock are called its structures.

The structures of igneous rocks may be broadly classified into two types:

1. Primary structures and
2. Secondary structures.

Primary structures: [2006, 2008, 2009, 2010, 2011]

Primary structures include all those features which are developed in igneous rocks at the time of cooling and consolidation of the magma or lava and immediately following it.

Example: stratification of sedimentary rock.

Important primary structures:

1. Flow structures: A flow structure is caused by the development of parallel or nearly parallel layers or bands or streaks in the body of an igneous rock.

II. Pillow structure: Sometimes when the lava is comparatively less viscous and more mobile, the upper surface of the lava will get solidified whereas the lava below the surface remains hot and capable of flowing.

III. Blocky and Roby structures: Higly viscous dry lavas under undergo very little flow before cooling and their congealed surface shows broken or fragmented appearance called a blocky structure. Such lavas are called blocky lavas. On the other hand very mobile lavas will flow for considerable distances, and their congealed surfaces will be smoothly wrinkled. Such structures are called ropy structures and such lavas are called ropy lavas.

iv. Spherulitic structure:

It is characterised by the presence of thin mineral fibres of various sizes arranged in a perfect or semi-perfect radial manner about a common centre. It is a common structural feature of hypabyssal and acidic volcanic rocks.

v. Orbicular structure:

It is characterised by the presence of ball-like segregations. Such type of structure is seen in some granites though not very occasionally.

vi. Rift and grain structure:

Many igneous rocks have a tendency of spliting more easily in two directions than in others. The direction of the most easiest parting is called the rift and the direction of next easiest parting is called the grain.

VII. Tension joints or columnar structure: As cooling and crystallisation of magma progresses the magma becomes increasingly rigid and ultimately gets subjected to cracking. For examples in formation of Basalts and some other fine grained or glassy igneous rocks, cracks or joints which are hexagonal in plan and resembles the mud cracks, are often developed at top layers of cooling magma.

VIII. Vesicular structure: Many lavas contain a lot of vapour and gases which escape out during their cooling and solidification. This may lead to the formation of cavities within the cooling mass. These cavities will remain empty during the initial periods of formation of rocks and the rock structure is called vesicular.

IX. Miarolitic structure: Sometimes, small and distinct cavities are formed during the crystallisation of magma. These small cavities may get filled up with some volatile matter which may probably enlarge their size and also facilitate formation of unusual minerals in a rock. These cavities often contain projecting distinct crystals and are called miarolitic structure.

Secondary structures: [2006, 2008, 2009, 2010, 2011] The structures developed in igneous rocks after their final consolidation, called secondary structures. They are in the forms of cracks, joints, shear zones, faults etc.

Some important igneous rocks:

Granites:

i. Granites are light coloured rocks of plutonic origin.

ii. Their colours are grey, pink or red.

iii. They are acidic in nature with quartz and feldspar as essential minerals.

iv. Granites are generally of coarse grained texture

v. Granites commonly occur in the form of large igneous bodies such as batholiths.

vi. It is extensively used as building stones for structural as well as decorative, monumental and architectural purposes.

Syenites:

1. Syenites can be compared to granites without any quartz.

ii. They are light coloured rocks of plutonic origin.

iii. Mineralogically they are of intermediate nature, lying between acidic and basic rocks.

iv. The essential mineral component of syenites is felspar.

v. They are generally coarse-grained to medium grained.

vi. They occur in association with granites in stocks and batholiths, though on a limited scale. They are rarely found rocks.

vii. It is of little commercial use as structural materials.

Diorites:

1. Diorites are light coloured granular igneous rocks with plutonic origin.

ii. They are intermediate rocks between acidic and basic rocks.

iii. Their silica content may vary between 52 to 66%.

iii. They consist of sodic or plagioclase felspar.
iv. They are coarse to medium grained
v. They rarely occur as batholiths.
vi. They are used more for crushed stone and for monumental and decorative purposes than for structural purposes.

Gabbros :

i. Gabbros are dark coloured usually greensish black igneous rocks with plutonic origin.
ii. Mineralogically they are basic in character.
iii. They consist of the calcic plagioclase felspar.
iv. They are coarse to medium grained rocks and are commonly equigranular.
v. Gabbros are fairly common rocks and are usually found in the forms of batholiths, stocks or bosses and dykes.
vi. Gabbros possess a high degree of compressive strength, low absorption.
vii. They are used for all types of structural work

Peridotites :

i. Peridotites are granular massive dark coloured igneous rocks with plutonic origin.

ii. They are ultra basic in nature with silica content less than 45% of the rock.

iii. They are essentially consist of ferromagnesian materials, chiefly olivine and with more or less pyroxenes.

iv. They are coarse to medium grained rocks.

v. They are commonly occur as intrusive igneous bodies in the forms of sills and dykes of moderate sizes.

vi. They are also found in association with gabbros.

vii. It is a rock in which diamonds are found.

Dolerites :

i. Dolerites are hypabyssal igneous rocks.

ii. They are dark in colour.

iii. They are basic to ultra basic in nature.

iv. They chiefly consist of calcic plagioclase felspar.

v. They generally exhibit fine grained texture.

vi. They are commonly occur as sills and dykes.

vii. They are highly tough and possess high abrasion resistance.

viii. they are generally used as crushed stones for concrete aggregates and for road marking.

Rhyolites:

i. Rhyolites are volcanic igneous rocks.

ii. They are generally light in colour and weight.

iii. They are acidic in nature.

iv. Its mineral composition is similar to that of the plutonic granite rock.

v. The essential minerals being quartz and felspar.

vi. They are generally fine grained rocks.

vii. They chiefly occur as lava flows or sheets.

viii. They are not as strong as plutonic igneous rocks and can often be used for ordinary construction work.

Andesites : i. Andesites are light coloured volcanic rocks.

ii. They are intermediate between acidic and basic rocks.

iii. The essential minerals are felspar.

iv. They are generally fine grained aphanitic rocks with typical porphyritic textures.

v. They occur in the form of lava flows of huge dimensions.

vi. They can be used as crushed stones.

Basalts : i. Basalts are the most important volcanic rocks and are found to occur in huge stocks.

ii. They are dark coloured volcanic igneous rocks.

iii. They are basic to ultrabasic in nature.

iv. Basalts are fine grained rocks

v. They occur in the form of huge lava flows.

vi. They are the most abundant of all types of volcanic rocks.

vii. Basalts are very tough stones and contain a lot of joints.

Sedimentary rock: [2005, 2008, 2009, 2010, 2011]

Sedimentary rocks are defined as those which are formed by the consolidation of sediments. The preexisting rocks are worn by various weathering agencies. The weathered product (i.e. sediment) is carried out to the water bodies like lake, ocean by the rivers where they accumulate and later by compaction and cementation form sedimentary or stratified rocks. About 75% of all rocks exposed on earth surface is sedimentary rock.

Example : i. Sandstone
ii. Limestone
iii. Shale
iv. Gypsum

Sediment:

Sediment is the loose and solid particles originate form weathering and erosion of pre-existing rocks that settle and accumulate in layers after being transported.

Classification of sediment by particle size:

1. Boulder > 256 mm
2. Cobble : 64 to 256 mm
3. Pebble : 2 to 64 mm
4. Sand : $1/16$ to 2 mm
5. Silt : $\frac{1}{256}$ to $\frac{1}{16}$ mm
6. clay < $\frac{1}{256}$ mm.

Formation of sedimentary rock: [2004, 2005, 2008, 2009, 2010, 2011, 2012, 2013]

Sedimentary or stratified rocks are formed by the following steps:

1. Weathering and erosion:

The pre-existing rocks when exposed to weathering and erosion agencies like atmosphere, wind, water, ice etc. disintegrate and break into finer fragments. The weathering and erosion is mechanical when there is only breaking down of solid rocks.

when the rock partly or wholly dissolve by chemical actions in water, it is called chemical weathering. The rate of chemical weathering depends on the temperature, the surface area and the amount of water. Mechanical weathering provides the large surface area necessary for chemical activity to take place near the surface of the earth. The main reactions involved in the process of chemical weathering be divided into oxidation, hydrolysis and carbonation. Oxidation is the reaction with atmospheric o gen to form an oxide. Hydrolysis is the reaction with water and carbonation is the reaction with atmospheric carbon dioxide to form a carbonate. The carbonation reaction begins with the uniting of carbon dioxide and water to form carbonic acid. The carbonic acid plays an important role in many weathering reactions which ultimately result in the production of new minerals.

2. Transportation: The product of rock weathering and erosion are commonly transported in large amount by running water (river), moving ice (glaciers) and blowing winds. Running water is the main transporting agents among the above three agents. The fragmentary particles of rock are carried in suspension depending upon their size, shape and velocity of transporting medium. The products which are dissolved in water are carried in solution.

3. Deposition: When the transported products are brought into oceans and lakes then their deposition starts. The product carried in suspension the coarser and havier particles settle first, followed by finer and lighter fragments. Thus the sediments are sorted out and deposited in the form of layers.

4. Lithification of deposited sediment: The transformation of loosely deposited sediment into a rock is called lithification. This job is generally accomplished in two ways i.e. by compaction or consolidation and by cementation. As the deposition of sediment continues it automatically goes on compacting and consolidating due to its own weight with the squeezing out of water. Fine grained sedimentary deposits such as shale and siltstone get effectively lithified by compaction. Certain mineral bearing solution provides the cementing materials and join the sediments together. The combined effect of consolidation and cementation results in the formation of hard and massive sedimentary rocks. When clay is present as bonding cement the rock will be poor and may possess grey or green-gray colour.

Types of sedimentary rocks: There are mainly three types of sedimentary rocks:

1. Clastic / Detrital rock: The rocks are composed of weathering products that do not dissolved into water, have silica (SiO_2) as one of their major components and are transported either by rolling along the bottom or in suspension are called clastic rocks.

Examples:

i. Conglomerate
ii. Shale
iii. Sandstone
iv. Siltstone
v. Mudstone

2. Chemical sedimentary rock: Sedimentary rocks formed by the crystalization of chemical precipitates are called chemical sedimentary rock. Dissolved materials precipitate from solution.

Examples:

i. Limestone
ii. Dolostone (called dolomite in the past).
iii. Rock gypsum
iv. Rock salt.

3. Biochemical sedimentary rock: The rocks are formed from organic processes that involve living organisms producing the sediments are called biochemical sedimentary rocks.

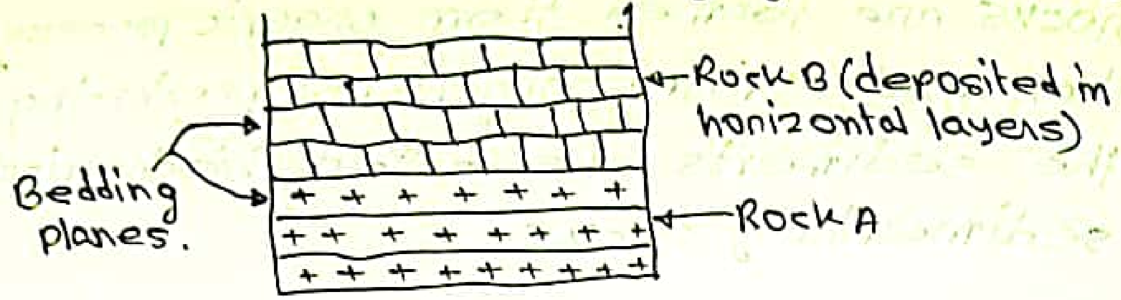
Examples: i. Most limestone
ii. coal.

Structures of sedimentary rocks:

The characteristic noticeable features which give conspicuous appearance to a sedimentary rock are called its structures. The various structures of sedimentary rocks can be classified into:

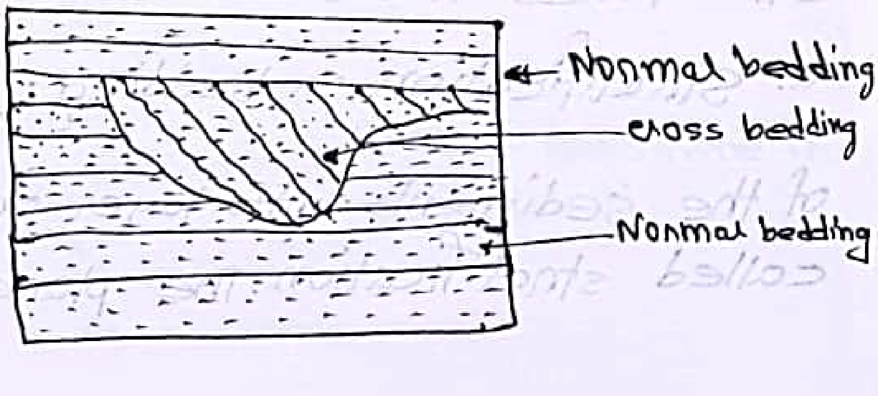
1. Mechanic structures: Mechanical structures include all those structures that have been developed in sedimentary rocks due to some physical processes operating at the time of deposition of sediments. The important mechanical structures include:

a. Stratification or bedding: The deposition of the sediments into layer or beds are called stratification. The plane dividing different beds are called bedding planes. Rocks beds are usually greater than 1cm.



The plane separating one bed from another is called a bedding plane. These bedding planes represent the planes of weaknesses in a rock.

b. Lamination and cross lamination: When the thickness of a bed is very small i.e. less than 1cm it is called a lamina and the deposit with laminae is said to be laminated. The laminae may be parallel to the bedding planes, or at an angle to them. Cross lamination is called cross bedding when the thickness of the unit involved is more than 1cm. Cross bedding is also called false bedding. Such bedding is a secondary bedding developed within the main beds of the sediments.

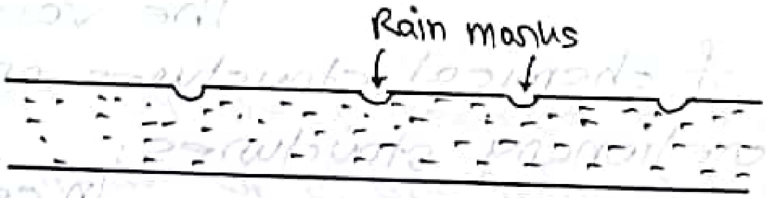


c. Ripple marks:

Ripple marks are the symmetrical or unsymmetrical undulations that may be seen on some sedimentary deposits. These are caused by winds or waves, during the deposition of sediments in a shallow water environment.

d. Rain marks:

The marks left by the falling rains on the loose sediments are called rain points or rain marks. Generally small hemispherical depressions are left as rain marks.



e. Joints and cracks:

In unconsolidated or partially consolidated sediment deposits, joints often develop because of shrinkage due to water loss, compaction and settlement or some other causes. These joints are characteristically short, irregular and discontinuous.

In the coarser sediments the fractured zone does not open out, to show any gaps but represents a zone of different and more open packing of particles.

However in the fine textured sediments especially clays wide cracks with gaps may open out permitting ingress of water. These easily seen mud cracks are roughly polygon in plan and V-shaped in section.

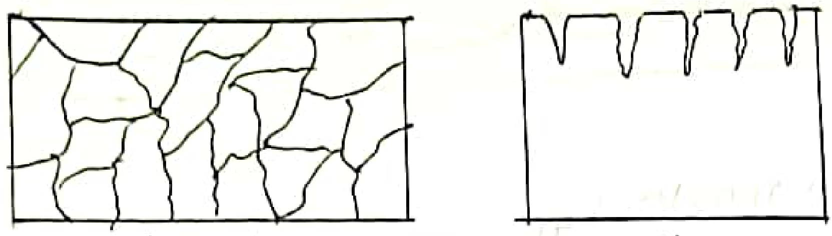
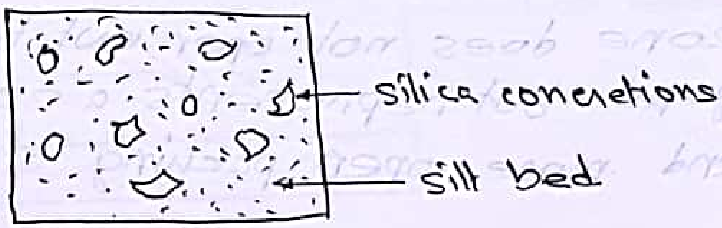


Fig: Mud cracks.

2. chemical structures: The various types of chemical structures are

a. concretionary structures: In certain sedimentary rocks, rounded bodies with irregular shapes are found embedded in the main rock masses. This foreign material generally differs from the adjoining rock masses, in its chemical as well as mineralogical composition. This material is called concretions and such a structure in a rock is called concretionary structure.



b. Oolitic and pisolitic structures:

Certain varieties of sedimentary rocks are made up of small spherical or rounded grains (0.1 to 1mm in size) resembling insect eggs in appearance. These particles are called oolitics and the rock is then said to have Oolitic structure.

When these spherical oolities are coarser in texture say more than 1mm in size the rock is said to have pisolitic structure. Certain organic Limestones have been found to exhibit such typical structures.

c. Geode structure:

Geode structure is presented by the presence of hollow shell which is made up of one mineral and contains lining of projecting crystals of another mineral inside the shell. The formation of a structure in a rock requires the presence of an original cavity.

3. Organic structures:

The importent organic structure is fossils. fossils are the remains of animals and plants being preserved in the rocks. They include all types of impressions, bones, shells skeletones etc. fossils are generally found in the sedimentary rocks.

Some important sedimentary rocks:

1. Breccias:

i. Breccias are mechanically formed clastic rudaceous sedimentary rocks.

ii. They consist of large angular fragments (more than 2mm in size) of heterogeneous compositions.

iii. Many breccias have been formed by volcanic eruptions and they are called volcanic breciass or agglomeratic breccias.

iv. They are generally formed at or near the places where the original pre-existing rocks disintegrates due to weathering.

v. They can be used for ornamental works.

2. Conglomerates:

i. Conglomerates are rudaceous clastic sedimentary rocks with the constituent fragments of more than 2mm in size.

ii. The fragments are rounded in shape

iii. They consist of rounded generally heterogeneous pebbles, gravels, boulders etc cemented together.

iv. They have undergone a lot of transportation through water before deposition.

v. Conglomerates generally occur as thick beds and have variety of colours and texturally present a heterogeneous appearance.

vi. They are used as crushed stones for roads, making concretes and as railroad ballasts.

3. Sandstones:

i. Sandstones are arenaceous clastic sedimentary rocks formed by the lithification of sand beds.

ii. The individual sand grains vary between 2mm to 0.1 mm.

iii. Quartz is the chief mineral constituent of sandstones.

iv. They may be of coarse or fine grained varieties.

v. They generally occur in thick or thin beds.

vi. They used for road construction and rail road ballast.

vii. Weak sandstones provide the most unsatisfactory material for dam foundations.

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4. shales : i. Shales are argillaceous clastic sedimentary rocks.

ii. They are formed by clay particles of less than 0.01 mm in size.

iii. They are generally soft and brittle rocks which crumble easily under hammer.

iv. The common clay minerals present in shales are kaolinite, montmorillonite and Illite.

v. They are very fine grained rock

vi. They usually occur as thin or thick beds.

vii. They are most abundent forming 70-80% of the sedimentary rocks of the earth's crust

viii. They are extensively used in the manufacture of clay products such as bricks, tiles, sewer pipes and portland cement.

5. Limestones : i. Limestones are the sedimentary rocks formed by chemical as well as organic processes.

ii. They are very important and wide spread sedimentary rocks.

iii. Pure limestones are composed of calcite and having specific gravity of 2.70.

iv. They are generally fine grained compact rocks.

v. They may be loosely packed or densly packed and thus exhibit clastic as well as interlocking textures.

vi. They generally compact and massive

vii. They generally occur as thin and thick beds upto 30m or more.

viii. They are largely used as crushed stones, for road making and for concrete aggregate etc.

6. Dolostones (Dolomite):

i. Dolostone is slightly heavier than limestone.

ii. Its specific gravity of 2.87.

iii. It is comparatively harder than limestone.

iv. It is widely used as crushed stone, in the manufacture of paper, in the production of magnesium and lime .

7. Rock gypsum:
i. It is composed of gypsum mineral.
ii. It has a chemical composition of $CaSO_4.2H_2O$.
iii. This rock is usually having micro crystalline texture.
iv. This is generally formed as a result of the evaporation from sea waters.
v. Usually occurs in association with the beds of rock salt.
vi. It is extensively used in the manufacture of many industries such as fertilizers, cement, plaster of paris and as a fire proof structural material.

8. Chert:
i. It is dense, hard and somewhat brittle.
ii. It is white to buff.
iii. It is commonly occur in association with limestones
iv. It is used as aggregates for making concrete.

9. Jasper:
i. It is dense, hard and brittle.
ii. It is generally red
iii. It is commonly associated with

ferruginous rocks.
iv. It is used as aggregates for making concretes.

10. Flint :
i. It is dense, hard and brittle.
ii. It is dark grey to black in color.
iii. It is abundant in chalk beds.
iv. It is used as aggregates for making concretes

11. Siltstone :
i. Siltstone is finer grained than sandstone but coarser grained than mudstone.
ii. It consists primarily of well sorted, rounded grains ranging between 3.9 - 62.5 μm.
iii. Siltstone is similar to shale except that it lacks fissility.

12. Mudstone :
i. Mudstone consists of very silt size and clay sized grains (< 0.0625 mm).
ii. They are often well consolidated with little pore space.
iii. They do not contain laminations or fissility but bedding plane features.

such as mud cracks or ripples.
iv. Mud cracks are formed by subaerial drying conditions.
v. Ripples suggest gentle wave activity or water movement during deposition.

13. kaolin :
i. kaolin consists of very fine-grained kaolinite clay weathered from feldspar minerals in metamorphic and igneous rocks.
ii. It is very light coloured to off-white.

Metamorphic rock :

A rock that has been changed from its original rock (parent rock) by metamorphic agents such as heat, pressure and fluid activity into a new rock (i.e. daughter rock) is called metamorphic rock.

These rocks change in appearance, mineralogy and sometimes even chemical composition from their parent rock source.

Metamorphism : [2013]

Metamorphism is the phenomenon in which the effects of heat, pressure and chemically active fluids bring about textural, structural and mineralogical change in the pre-existing rock.

Formation of metamorphic rock :

The formation of metamorphic rocks takes place in the solid state although some kinds of metamorphic processes take place in the presence of hot liquids and gases chiefly water.

The igneous and sedimentary rocks when subjected to metamorphism, undergo changes that are either physical chemical or both. Physical changes are reflected as changes produced in the texture of the old rocks whereas chemical changes produce the formation of new minerals thus giving rise to this new group of rocks called metamorphic rocks.

For example: Granite is an igneous rock which on metamorphism produces a metamorphic rock called gneiss.

Causes of metamorphism/metamorphic agents:

There are three factors which are responsible for producing metamorphism.

1. Heat:

i. Heat provides energy for chemical reactions to proceed resulting in new minerals to form from original minerals in the source rock.

ii. Heat provides the energy that enables individual ions in the rock to mobilize and migrate between other ions recrystalizing and forming into new minerals.

iii. Heat involved in metamorphism comes from two main sources:

a. Heat transferred during contact metamorphism from magma

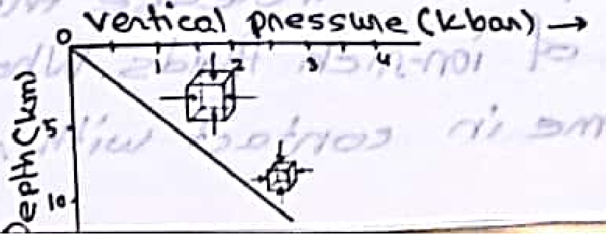
b. Progressive temperature increase associated with geothermal gradient as rocks are transported to greater depths below the earth's surface.

2. Pressure:

The pressures which cause metamorphism is of two different kinds.

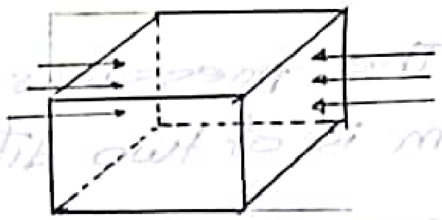
i. Uniform pressure:

Uniform pressure increases with depth. It acts vertically downward and affects the volume of both liquids and solids. Naturally its effect is significant only at great depths but not at or near the surface. This also means that high temperature will also be associated with high uniform pressure. So both of them act together and bring about metamorphism in rocks.



Atmospheric pressure at sea level = 1 bar

ii. Direct pressure: The direct pressure which is also known as stress, is due to the tectonic forces. Such pressure acts in any direction. It affects the shape of rocks or minerals. It is effective in the upper layers of the crust and increase with depth to some extent. The application of stress gives rise to shearing movements in the rock and produces new minerals. One direction of squeezing is much stronger than the others and minerals align themselves to reduce stress.



3. Chemically active fluids:

Chemically active fluids play a key role in different ways in causing metamorphism.

chemically active fluids that are present between mineral grains during metamorphism act to facilitate ion movement and the re-crystallization of existing and new minerals.

Higher temperature increase the reactive capability of ion-rich fluids. When these fluids come in contact with mineral grains, the grains readily dissolve because of differential chemical potentials and ions migrate to areas of lower potential eventually recrystallizing.

Chemically active fluids have the ability to move between different rock layers and transport ions from one rock to another rock before they recrystallize.

Role of parent rock in metamorphism:

I. Parent rock provides the mineral and ion sources that are transformed into new minerals and rocks.

II. In most cases the new metamorphic rock has the same chemical composition as the parent rock that they formed from.

Examples:

1. Sandstone (sedimentary) → Quartzite (metamorphic)
2. Granite (Igneous) → Gneiss (metamorphic)
3. limestone (sedimentary) → Marble (metamorphic)

Types of metamorphisms: [2004, 2006, 2007, 2013]

1. Contact or thermal metamorphism:

It occurs when parent rock is intruded by magma (usually an igneous intrusion). Metamorphic changes under these conditions are primarily the result of temperature changes associated with the intruding magma. Additionally when hot ion-rich water circulates through fractures in a rock, it can also cause chemical changes to the parent rock. These heat driven, chemical reactions occur with igneous activity and presence of water.

2. Dynamic metamorphism:

It occurs when rocks are subjected to extreme pressure very rapidly. Two situations are noted:

a. Fault zone:

In the upper crust faults are planar zones of crushed rock. The heat generated by friction during faulting can melt and metamorphose portion of the rock.

b. Impact craters:

Impact craters formed by extra-terrestrial objects colliding with the earth are commonly identified by exotic high pressure minerals formed during the meteorite crash. Stishovite and coesite, both are high pressure forms of quartz resulting from meteor impacts.

3. Regional metamorphism: It occurs when rocks are subjected to both heat and pressure on a regional scale. It is caused by burial deep in the crust and is associated with large scale deformation and mountain building. It is the most widespread form of metamorphism.

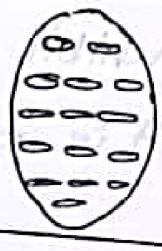
Types of metamorphic rock:

Metamorphic rocks can be classified based on their physical appearence as:

1. Foliated rocks: If the rocks exhibit parallel or sub-parallel orientation then it is called foliated rocks.

2. Non-foliated / massive rock: If the rocks do not exhibit orientations then it is called non-foliated rock.

Difference between foliated and non foliated rocks. [2015]

Foliated	Non-foliated
Complex composition, many different kind of minerals.	Simple composition, only a few minerals.
Formed under directed pressure	Formed under uniform pressure.
Many new minerals produced with a change in temperature or pressure	No new minerals produce with a change in temperature or pressure
Texture is layered and lineated	Texture is granular and equidimensional
Minerals have a prefered orientation	No prefered orientation
Examples: Slate, Gneiss, Schist.	Examples: Marbel, Quartzite
	

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Some important metamorphic rocks:

1. Gneisses :

A gneisses may be defined as any banded or layered metamorphic rock, whether originally of igneous (Granite, Syenite etc) or sedimentary (conglomerate) origin. The bands are mineralogically unlike and consist of interlocking mineral particles which are generally large enough to be visible by the naked eye. These bands of gneisses are generally of contrasting colors, textures and compositions. The thickness of bands may vary from a fraction of a centimeter to many centimeters. Gneisses may vary in color from white to black throughout various shades.

2. Schists :

Schists are crystalline foliated metamorphic rocks in which the individual folia are mineralogically alike and the principal minerals are visible through the naked eye. The rock predominantly consists of platy and flaky minerals such as micas, chlorite, sericite, Talc, Hornblends etc. Schist exhibit uniform bands or foliations with the typical

Schistose structure. They are commonly coarse grained crystalline rocks, sometimes showing prophyroblastic texture.

3. Phyallites :

Phyallite is formed in the second or intermediate stage of complete metamorphism of shale (a sedimentary rock) which on first stage metamorphism produces slate, which on second stage metamorphism produces phyallite and finally in third stage metamorphism changes into Mica schist. It is a fine grained foliated rock. The individual minerals are not recognisable by naked eye but presence of well developed Muscovite flakes can be seen on close observation and is indicated by the shining cleavage surface.

4. Slates :

slate is an extremely fine textured Metamorphic rock, formed by the metamorphism of shale. In fact slate represents the first stage metamorphism in the progressive metamorphism of argillaceous. slates. It is a foliated rock and possesses a typical slaty rock cleavage as secondary structure. which enable it to split easily into thin smooth sheets. This typical slaty cleavage is produced in this rock due to parallel arrangement of platy or flaky minerals under the influence of metamorphism. Slates are rather soft rocks which can be easily cut into sheets and pieces. They are widely used in electrical industries as switch boards, bases and various turned and shaped parts.

Quartzite:

Quartzite is a siliceous metamorphic rock formed by the contact or dynamic metamorphism of sandstone (a sedimentary rock). They are fine-grained, hard and compact crystalline rocks. Quartzites differ from sand-stones mainly in their greater hardness, denseness and crystalline character. Quartzite essentially contain quartz mineral. They form excellent road metals and are widely used as crushed stones for concrete aggregates, road aggregates and rail road ballasts.

Marbles :

Marbles are calcarious, compact crystalline granular rocks formed by the metamorphism of limestones generally and dolostones occasionally. Pure marbles are massive. generally non foliated but when impurities like micas are present in sufficient amounts, they may exhibit slight foliations due to the layered arrangement of these minerals. Such foliated or banded marbles are not so durable in a severe climate nor do they take a continuous polish. Pyrite and termolite are also objectionable impurities.

Marbles are extensively used as building stones, especially for ornamental and decorative purposes in columns, pilasters, stair cases, floor etc.

Rock cycle: [2004, 2006, 2009, 2010, 2011, 2012, 2013, 2015, CT-13]

According to Bates & Jackson rock cycle is a sequence of events involving the formation, alteration, destruction, and reformation of rocks as a result of natural process.

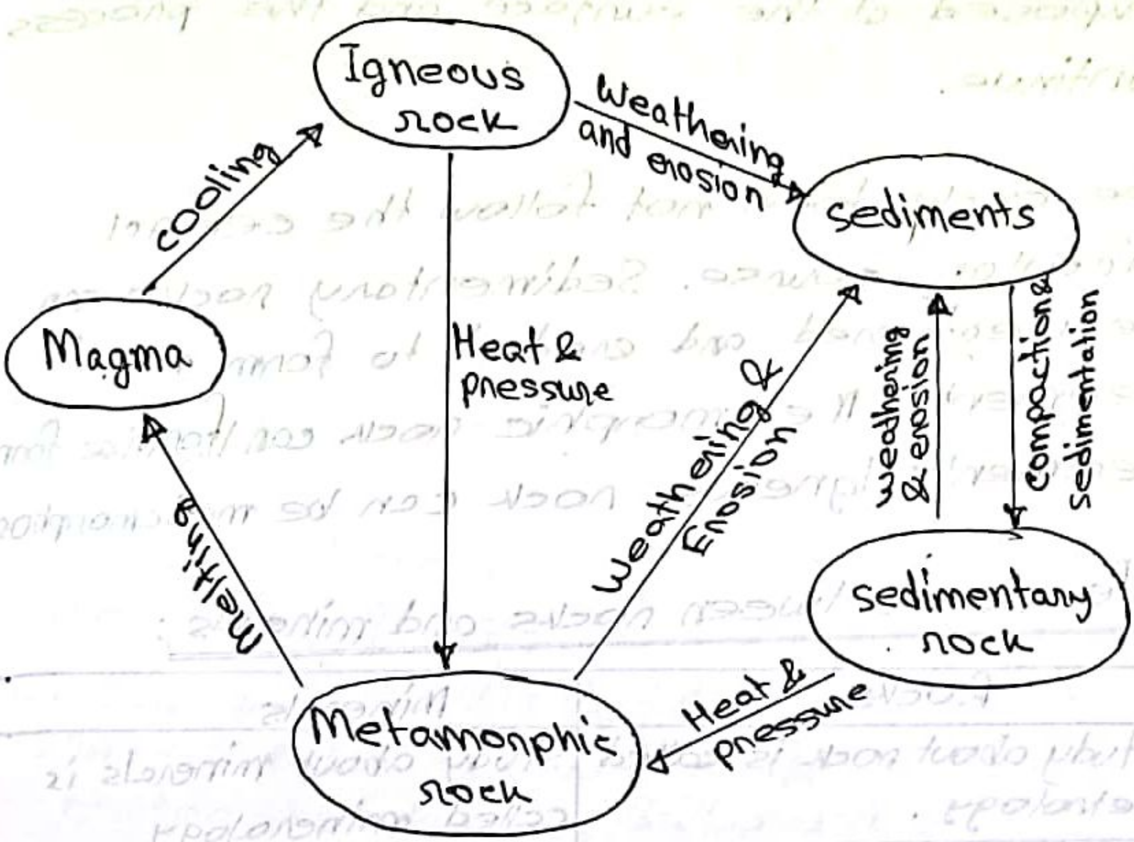


Fig: Rock cycle.

The three groups of rocks i.e. igneous rock, sedimentary rock and metamorphic rock are related to each other by rock cycle. Igneous rock at the surface of the earth are subjected to weathering and erosion. Material derived from this is deposited to form sediments. The loose sediment consolidates to form a sedimentary rock. This sedimentary rock becomes buried and subjected to heat and pressure to form metamorphic rock. This metamorphic rock begins to melt and form magma. The igneous rock is found from this magma by cooling. This can be exposed at the surface and the process continue.

The cycle does not follow the central circular course. Sedimentary rocks can be weathered and eroded to form new sediments. Metamorphic rock can likewise form sediments. Igneous rock can be metamorphosed.

Difference between rocks and minerals:

Rocks	Minerals
Study about rock is called petrology.	Study about minerals is called mineralogy
Does not have a define chemical composition	Has a definite chemical composition.
colour is not the same	Usually the same colour.
It has no definite shape	Has usually a define shape
Rock has some fossil	It has no fossil.
Rocks used for shelter and foundation	Minerals used for bone and tooth formation and blood coagulation.
Examples: Limestone, coal, claystone, Basalt	Examples: Gold, silver, Fluorite etc.

STRUCTURAL GEOLOGY

structural geology: [2006, 2008, 2015]

The study of all the major and minor structural features like folds, faults, joints etc. constitute a separate branch of geology is called structural geology.

Technical terms of structural geology:

1. Strike: [2004, 2006, 2008, 2011, 2016]

Strike refers to the direction in which a geological structure (such as a bed, a fault plane, or a joint plane) is present. When an inclined bed is suitably exposed on the surface, its direction of occurrence, its direction of inclination and amount of inclination can be actually measured directly by a clinometer (a magnetic compass like instrument).

The strike direction may be defined as the direction of the trace of the intersection between the bedding plane and a horizontal plane.

2. Dip : [2004, 2006, 2008, 2011, 2016]

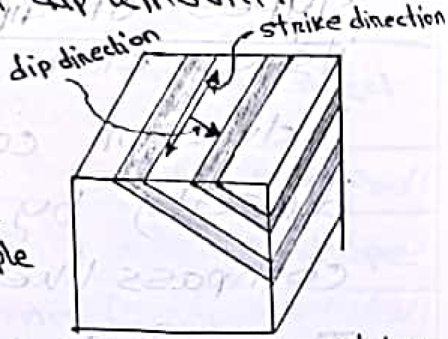
Dip literally means slope or inclination. In structural geology dip is expressed both as direction and amount.

The dip direction is the direction along which the inclination of the bedding plane occurs.

The dip amount is the angle of inclination between the bedding plane and a horizontal plane.

True dip direction: In a direction perpendicular to the strike direction, the inclination of bedding planes will be maximum and this is called true dip direction or simply dip direction. And the amount of of inclination along this direction is called the true dip amount.

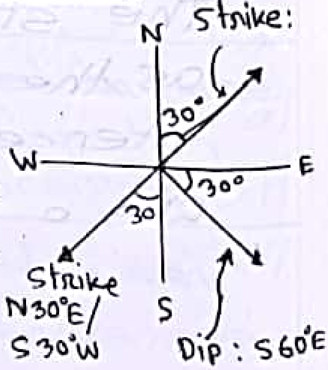
Apparent dip: The innumerable directions which lie in between the strike direction and true dip direction are known as apparent dip direction and the inclination along them are called apparent dip amount.



Expression of strike & dip: [2016]

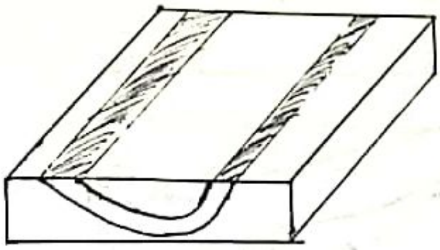
The strike direction is expressed in two ways i.e. with reference to north and south. For example N30°E or S30°W.

The dip direction can be given in only one definite direction which is perpendicular to the strike direction. For the preceding example of strike direction the dip direction will be either N60°W or S60°E. only.



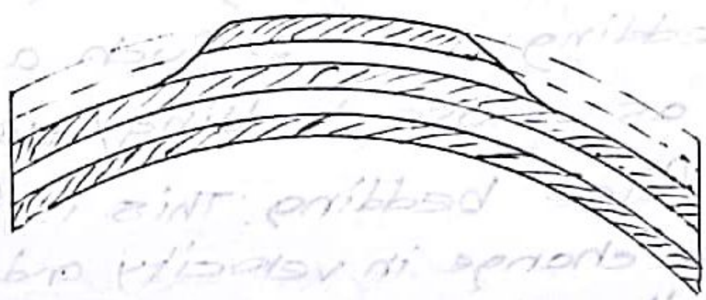
3. Outcrop:

It is the actual area exposed by a bed on the surface of the earth. It is affected by the angle of dip. Outcrop is less for vertical dip than the dipping at some angle.



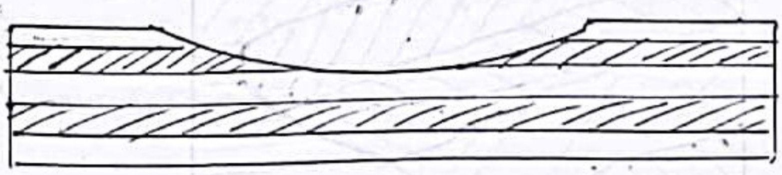
4. Outlie

It is an isolated patch on yougen rock surrounded by geologically older rocks on all sides. Generally it happens on high grounds due to excessive erosion on all sides, whereas a certain patch proves resistant to weathering.



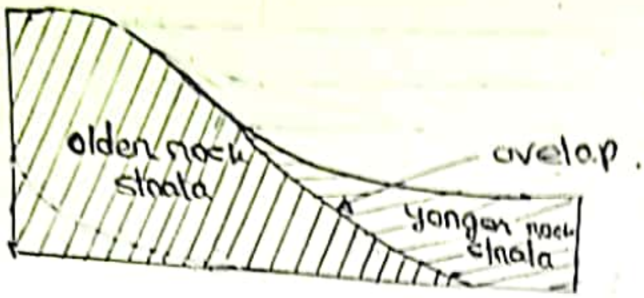
5. Inlier:

It is an outcrop of older olds, structure surrounded by geologically younger rocks on all sides. Generally it is a result of denudation found in valleys and depressions.



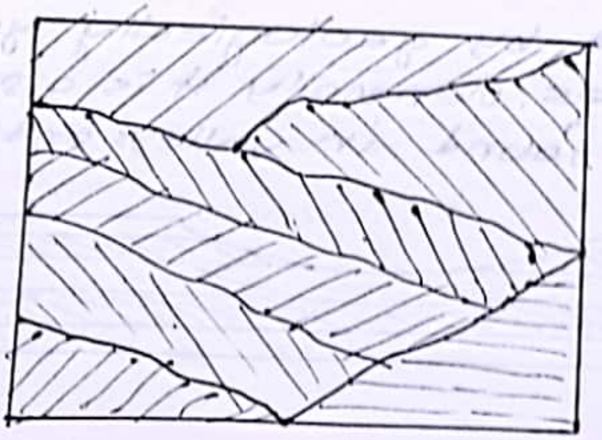
6. Overlap : [2001 2008, 2009, 2012]

An overlap is a particular type of an unconformity in which the overlying (younger) strata extends so as to overlap the underlying (older) strata.



7. Cross bedding :

Sedimentary rock beds or layers are parallel to one another. But sometimes it has been observed that the beds lie slightly oblique to the major bedding planes. Such a structure is known as cross bedding/ current bedding / false bedding. This is formed due to the change in velocity and direction of flow of the stream or wind depositing the rock particles.



Types of geological structure:

Most commonly found geological structures in nature are:

1. Unconformities.
2. Folds.
3. Faults.
4. Joints.

Unconformity: [2005,2009]

If a major breaks occur in sedimentation in between two sets of comfortable beds, it is called an unconformity.

A junction separates two units of rocks that lie upon another is known as unconformity. The upper unit is younger than the lower unit.

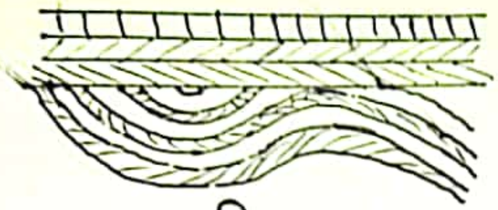
Types of unconformity:

There are two main types of unconformity.

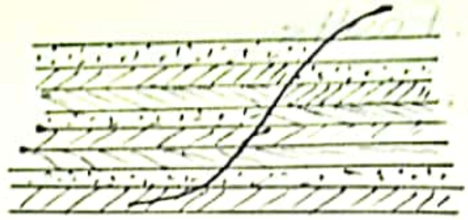
1. Non conformity:

It is a term used for an unconformity when the upper units lie over a non-stratified rocks (igneous or metamorphic).

ii. **Disconformity:** It is a term used for an unconformity when the upper unit as well as the lower unit are practically parallel but the junction between the two units is or uneven.



Non conformity

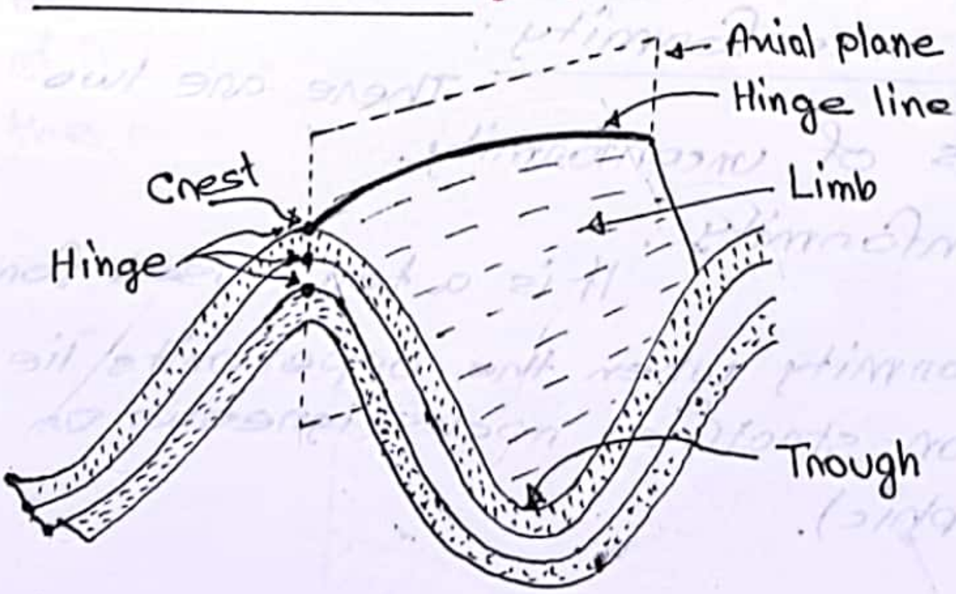


Disconformity.

Folds:

Folds may be defined as undulations or bend or curvature developed in a rock because of stress which are acting on rocks from to time in past history of the earth.

Parts of folds: [2013, 2015, 2016]



i. Limbs / Flanks:
Lims on flanks of the fold is the sloping side from the crest to the trough.

ii. Hinge:
In a folded layer a point can be found where curvature is maximum is called hinge.

iii. Hinge line:
When the rocks occur in the sequence and all the hinge points are joined together then they make a line called hinge line.

iv. Axial plane:
It is the imaginary plane that passes through all points of maximum curvature in folded sequence. It may be vertical, or horizontal in nature.

v. Axis of the fold:
It may be defined as a line parallel to the hinge line of a fold. Or it may be defined as line of intersection of a axial plane of a fold and with any bed of the fold.

vi. Plunge of fold: plunge is the angle which axis line makes with a horizontal plane.

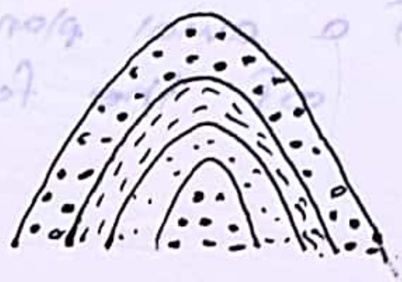
vii. Crest: The line running through the highest point in an uparched fold is called crest.

viii. Trough: The line running through the lowest point in a downarched fold is called trough.

Classification of folds:

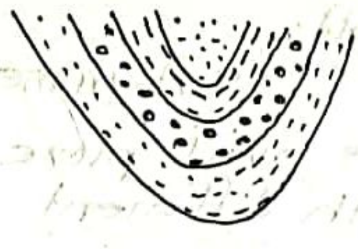
1. Based on the nature of bending:

a. Anticline fold: [2001, 2007, 2010, 2012, 2016]
An anticline is a fold that arches up as both sides of the rock are pushed inward. Anticline creats the type of fold that looks like an letter 'A'.



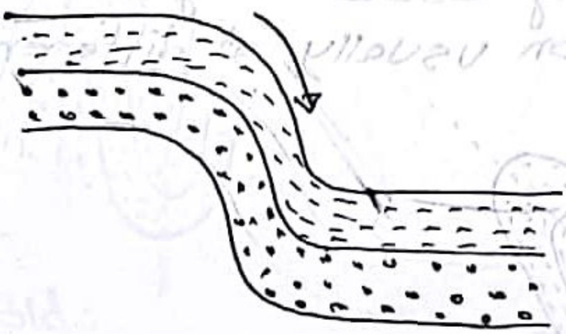
b. Syncline fold: [2010, 2012, 2013]

A syncline is a fold that sinks down as both sides of the rock are pushed inward.



c. Monocline fold:

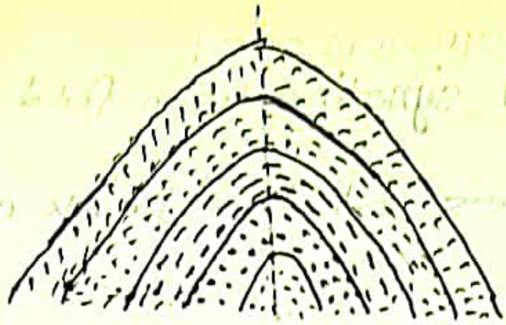
A monocline is a fold where the rock layers form an 's' shape as the sides of the rocks are compressed. All the layers of rocks are still horizontal. Monoclines are layers in only one direction.



2. Based on the position of axial plane:

a. Symmetrical fold:

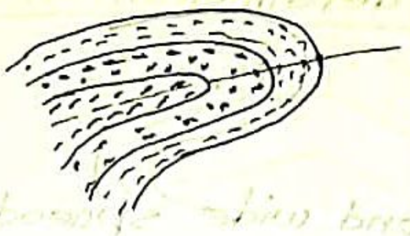
A symmetrical fold is one in which the axial plane is vertical. In this fold the limbs are of equal length.



b. Asymmetrical fold: An Asymmetrical fold is one in which the axial plane is inclined on the folds with different angles. Limbs are unequal in length.

c. Overturned fold: [2006, 2007, 2008, 2016] It is an asymmetrical fold with inclined axial plane in which both the limbs are dipping essentially in the same general direction usually at different angles.

d. Recumbent fold: [2005, 2010, 2012] This is the extreme types of overturned folds, in which the axial plane becomes nearly horizontal. In such fold the upper limb is called normal limb and the lower limb is called inverted or reverse limb.



e. Isoclinal fold: [2007]

Folds having parallel limbs are called isoclinal folds. In such folds the limbs dip at same angle and same direction.

Isoclinal fold is tree types:

i. Inclined

ii. Vertical

iii. Recumbent

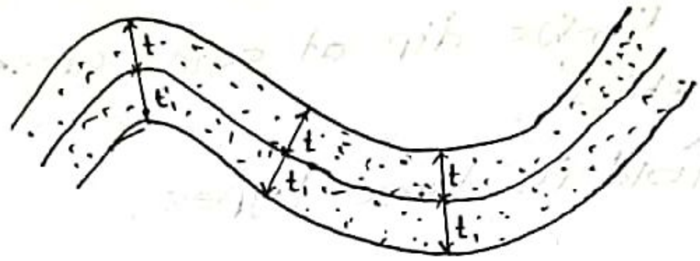
f. Box fold:

In such type of folds the crest is broad and flat and two hinges are present.

3. Based on intensity of deformation on degree of compression: [2004]

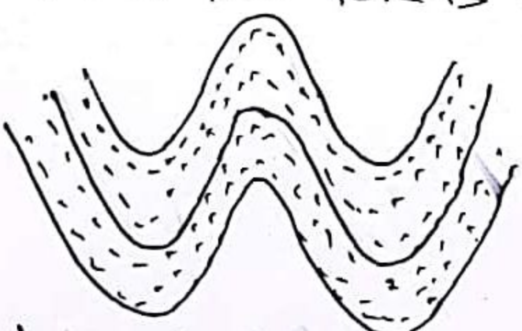
a. Open fold:

The gentle and wide spread fold produce due to mild intensity of deformation is called open fold. In this fold the thickness of the rock remains unchanged.



b. closed fold:

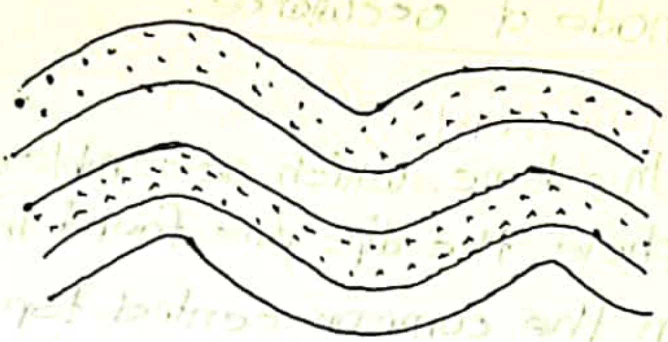
When the intensity of the deformation is high and the beds are thinner at the limbs and thickening at the crest then the fold is called closed fold.



4. Based on the behaviour of depth.

a. Parallel fold:

In such type the folded layers are parallel and the curvature is greatest at the centre reduces upwards in case of upfold and downwards in case of downfold.



b. Similar fold:

Curvature of the folded surfaces are similar and it is thickened at the hinge and thin along the limbs.

c. Supratenuous fold:

A fold in which the beds are thinner at the crest and thicker at the trough and the folding is accompanied by erosion and deposition.

5. Based on the profile of the outer surface:

a. Chevron fold:

In this fold the hinges are sharp and angular.

b. Fan fold:

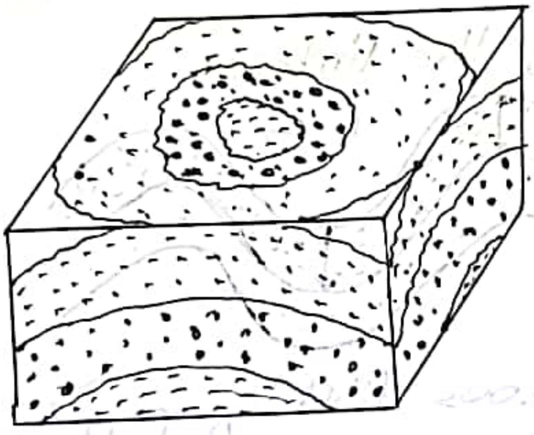
In this fold both the limbs are overturned.

6. Based on mode of occurance:

a. Domes : [2012, 2015]

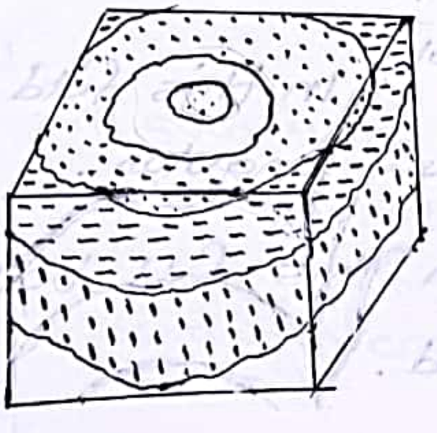
In a dome, which resemble's an upper hemisphere, the dips are found in all sides from the common central top point. Thus this is a type of anticline.

Domes are caused by compression and uplift.



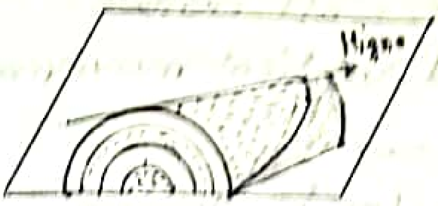
Basins: [2012, 2015]

In a basin which is like a bowl and the slopes are just opposite of domes, the dips are found towards a common central bottom point from all sides. This is a type of syncline. This is caused by compression and downwarping.



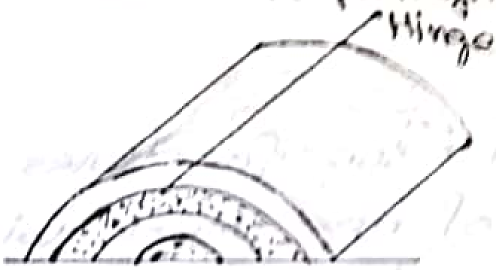
Plunging fold:

A fold in which the top of the axial plane is dipping in a vertical plane is called plunging fold.



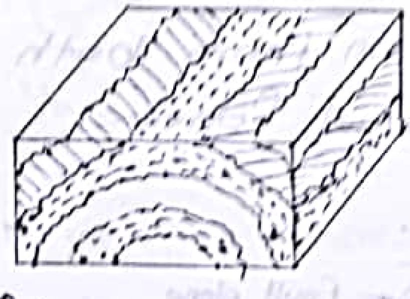
Non-plunging fold:

A fold in which, the top of the axial plane is not dipping in a vertical plane is called non plunging fold.



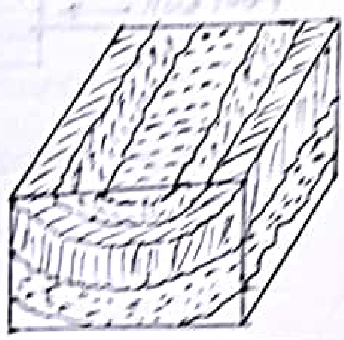
Anticlinorium: [2002]

An exceptionally large sized fold in which the trend of the folding is anticlinal in character is called anticlinorium.



Synclinorum:

An exceptionally large sized fold in which the trend of the folding is synclinal in character is called synclinorium.



Causes of folds : [2005]

1. Tectonic causes :
    a. Lateral compression
    b. Igneous intrusive
    c. Salt domes
    d. Vertical movements

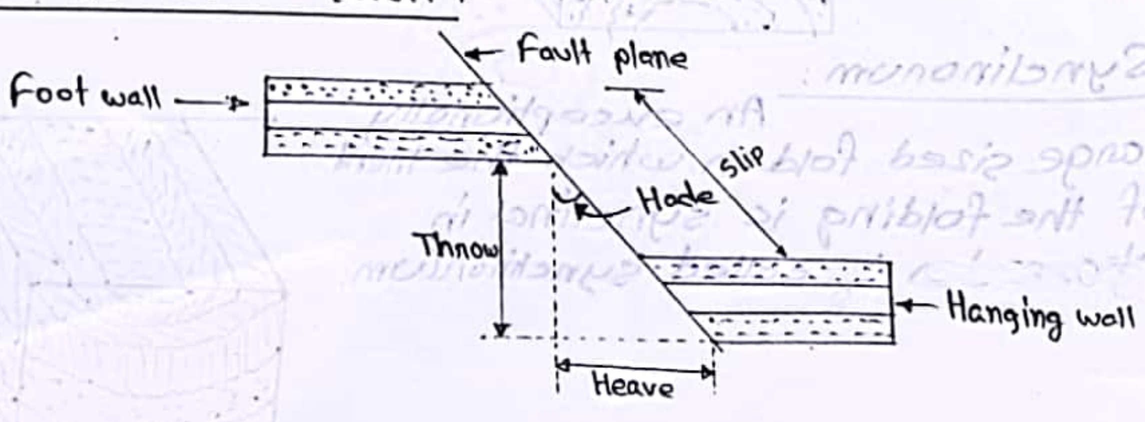
2. Non-tectonic causes :
    a. Land sliding
    b. Creeping
    c. Differential compaction
    d. Solution
    e. Glaciation.

Faults :

Faults are fractures along which movement of one block with respect to other has taken place. This movements may vary from a few centimeters to many kilometers depending upon the nature and magnitude of the stresses and the resistance offered by the rocks.

Faults can occur from both tensional and compressional forces.

Parts of a fault :



1. Fault plane:
A plane along which the rupture has taken place and one block has moved with respect to other is known as fault plane. This plane is generally formed along the line of least resistance.

2. Hanging wall:
The upper block on the block above the fault plane is called hanging wall.

3. Foot wall:
The lower block on the block below the fault plane is called the foot wall.

4. Hade:
It is the inclination of fault plane with the vertical is called hade.

5. Throw:
It is the vertical displacement between the hanging wall and the foot wall.

6. Heave:
It is the horizontal displacement between the hanging wall and foot wall.

7. Slip: It is defined as the relative movement of the block present on either side of a fault plane.

Causes of faulting:

Interior of the earth is cooling day by day which causes some shrinkage in the earth's crust. This shrinkage is responsible for the stresses to be developed within the earth's crust. These stresses when greater in magnitude exert on much pressure that the layers of earth's crust are folded due to compressive stresses and afterwards when the stresses are released fractures are formed. If the stresses still continue the blocks move up and down along the fault plane causing faults.

This generally happens when the rocks are stressed beyond elastic limit.

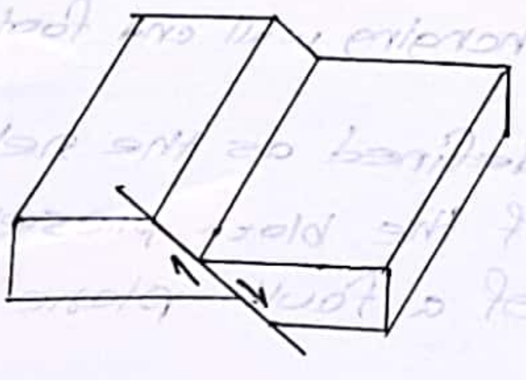
Faults are caused due to earthquake also.

Classification of fault:

1. On the basis of net slip

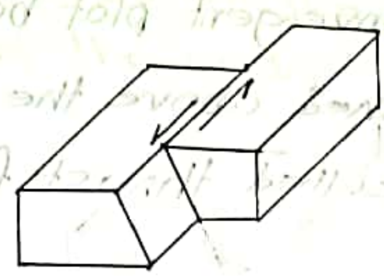
a. Dip slip fault:

The fault in which the slip takes place along the direction of the dip is called dip slip fault. In this fault the net slip is parallel to the dip of fault.



b. strike slip fault:

The fault in which the slip takes place along the direction of the strike is called strike slip fault. In this fault the net slip is parallel to the strike.



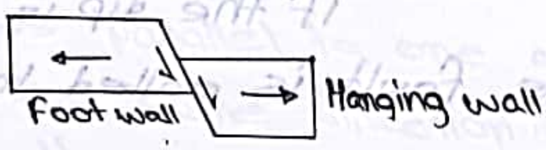
c. Oblique strike fault:

When the net slip is neither parallel to strike nor parallel to the dip direction is called oblique strike fault.

2. Based on the movement of block:

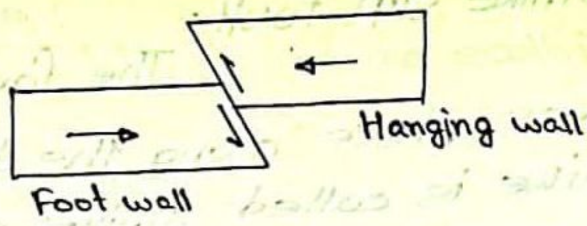
a. Normal fault: [2002]

Normal fault occurs when tensional force acts in opposite directions and cause foot wall moves up relative to the hanging wall.

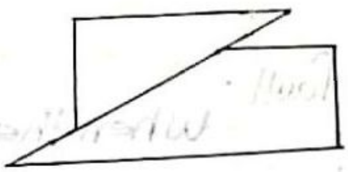


b. Reverse fault: [2005, 2006, 2007, 2008, 2009, 2010, 2016]

Reverse fault is one in which the hanging wall moves up relative to the foot wall due to compression.

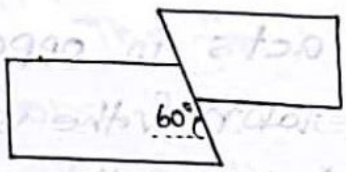


c. Thrust fault:
At convergent plat bounderies the older rocks pushed above the younger rocks and this is called thrust fault.

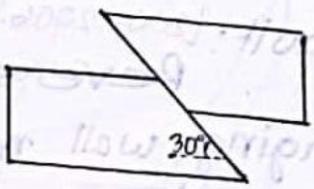


3. Based on the dip angle:

a. High angle fault:
If the dip is greater than 45° then the fault is called high angle fault.



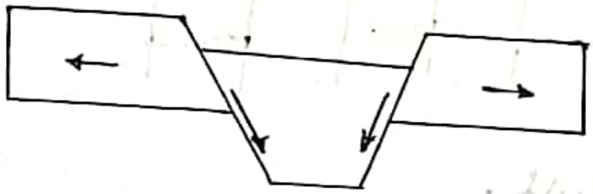
b. Low angle fault:
If the dip is less than 45° then the fault is called low angle fault.



4. Based on the fault pattern:

a. Graben or rift fault: [2013]

A graben or rift fault is one which produced when tensional stress result in the subsidence of a block of the rock.

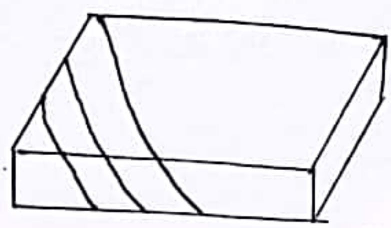


b. Horst fault: [2005, 2006]

A horst fault is one which produced when compressional stress result in the pushed up of a block of rock.

c. Parallel fault:

A series of faults running more or less parallel to one another and all handing in the same direction are called parallel fault.



d. Step fault : [2013]

It consists of those parallel faults where down throw of all are in the same direction and it gives a step like arrangement.

e. Radial fault :

A number of faults exhibiting a radial pattern are described as radial fault.

f. Peripheral faults :

Curved faults of more or less circular or arc like outcrops on level surface are called peripheral faults.

g. Enechelon fault: Enechelon faults are comparatively short faults which overlap each other.

5. Based on the altitude of fault relative to the altitude of the adjacent rocks:

a. Bedding fault: A fault whose fault plane is parallel to the bedding plane of the constituent rock.

b. Oblique fault: When the strike of the fault plane is oblique to the strike and dip of strata it is called an oblique fault.

c. Tear/Transcurrent/wrench fault: A fault occuring in the rocks above a low angle thrust fault and striking approximately at right angles to the strike of the thrust fault.

Nappe: [2005]

A nappe or thrust sheet is a large sheetlike body of rock that has been moved more than 2km above a thrust fault from its original position.

Klippe: [2012]

A klippe is defined as an isolated erosional remnant of an over thrust sheet. During overthrust faulting the hanging wall generally moves over the foot wall for considerable distances.

WEATHERING &
EROSION

WEATHERING

Weathering: [2013, 2016]

Weathering is the process of breaking down rocks near the surface of the earth.

Factors influencing weathering: [2007, 2008, 2009, 2010, 2011, 2013]

A. Endogenetic factors (Factors are related to the rock characteristics):

i. Hardness:

Weaker rocks get weathered more easily than stronger rocks

ii. Joints and lines of weakness:

The presence of joints and lines of weakness make more vulnerable to weathering.

iii. Mineral and chemical composition:

Mineral and chemical composition determine the degree of susceptibility to weathering.

iv. Colour:
Usually more stable minerals are light coloured while less stable ones are dark coloured.

v. Texture:
Usually fine grained rocks weather more quickly than coarse-grained ones structure.

B. Exogenetic factors (factors other than rock characteristics):

i. Climate

ii. Precipitation

iii. Acids

iv. Solution

v. Temperature.

vi. Animals

vii. Plants.

Classification of weathering: [CT-Influence14]

There are mainly two types of weathering.

1. Physical / Mechanical weathering

2. Chemical weathering.

Physical weathering: [2012]

Physical weathering is the disintegration of parent rocks into smaller rock fragments without changing chemical composition of parent rocks. Physical weathering is also known as mechanical weathering.

Important agents of physical weathering:

i. Exfoliation

ii. Frost action

iii. Formation salt crystal

iv. Effects of plants and animals.

i. Exfoliation:

When a rock mass is exposed by weathering and removal of the overlying rock, there is a decrease in the confining pressure on the rock. and the rock expands. This unloading promotes cracking of the rock is known as exfoliation.

Granitic rock tends to exfoliate parallel to the exposed surface because the rock is typically homogeneous and it doesn't have predetermined planes along which it must fracture.

Sedimentary and metamorphic rocks tend

to exfoliate along predetermined planes.

II. Frost action:

Frost wedging is the process by which water seeps into cracks in a rock, expands on freezing and thus enlarges the cracks. The effectiveness of frost wedging is related to the frequency of freezing and thawing.

III. Formation of salt crystal:

When salt water seeps into rocks and then evaporates on a hot sunny day, salt crystals grow within cracks and pores in the rock. The growth of these crystals exerts pressure on the rock and can push grains apart causing the rock to weaken and break.

IV. Effects of plants and animals:

The effects of plants and animals are significant in physical weathering. Roots can force their way into even the tiniest cracks and then they exert tremendous pressure on the rocks as they grow, widening the cracks and breacking the rock.

Although animals do not normally burrow through solid rock, they can excavate and remove huge volumes of soil and thus expose the rock to weathering by other mechanisms.

Chemical weathering:

Chemical weathering is the disintegration of rockmass or parent rocks into smaller rocks with changing chemical composition of the parent rocks. Chemical weathering disintegrates the rock entirely or might simply become softer and more vulnerable to other forms of weathering.

Factors affecting chemical weathering:

[2016]

1. Oxidation
2. Hydrolysis
3. Carbonation
4. Acid rain.

1. Oxidation:

Oxidation is the reaction of oxygen with chemicals in a rock. For instance, oxygen reacts with iron to form iron oxide known as rust which is soft and vulnerable to physical weathering.

2. Hydrolysis:

Hydrolysis is a process in which a rock absorbs water into its chemical structure. A rock with a higher water content is softer and thus easier for physical weathering or even just gravity to decay.

3. Carbonation:
Carbonation is caused by carbonic acid in water reacting with and degrading rock. This acid is especially effective at degrading limestone. Underground carbonation may form limestone caverns.

4. Acid rain:
Acid rain is caused by sulfur and nitrogen compounds in the air reacting with water to form acids that then fall to the ground. These acids are particularly harmful to marble, chalk and limestone and tombstones, statues, and other public monuments.

Exogeneous process of weathering: [2016]
Exogeneous process of weathering is the process which comes from the forces on or above the earth's surface. Physical and chemical weathering process is the exogeous process of weathering.

Write short notes on weathering grade and its engineering significance : [CT- Influence 14]

Weathering grade is the engineering classification of rock based on the degree of weathering.

Grade	Term	Description
VI	Residual soil	All rock material is converted to soil. Original mass structure is destroyed.
V	Completely weathered	All rock material is decomposed to soil. Some remnant original structure
IV	Highly weathered	More than half of rock material is decomposed to soil
III	Moderately weathered	Less than half of the rock material is decomposed to soil.
II	Slightly weathered	All the rock material may be discolored by weathering and some may be weaken than its original fresh rock.
I	Fresh rock	clean rock

Engineering significance of grading:

1. State of weathering of rock can be easily found which is important for a definite project.

Scanned with CamScanner

ii. Higher grade indicate less bearing capacity of rock

iii. Higher grade decreases strength of rock

EROSION

Erosion:

Erosion is the process of removing earth materials from their original sites through weathering and transport.

Agents of erosion: [2005, 2012]

There are five agents of erosion:

1. Gravity
2. Running water
3. Glaciers
4. Waves
5. Wind.

How does gravity cause erosion?

Mass movement is an erosional process that moves rocks and sediments downslope due to the force of gravity.

There are various mass movements. They are

i. Lanslides:

This is the most destructive mass movement. It is when rock and soil slide quickly down a steep slope.

ii. Mudslide:

It is a rapid downhill movement of a mixture of water, rock and soil. It is usually occurs after heavy rains in normally dry areas.

iii. Slump:

Slump is a mass of rock and soil suddenly slips down a slope. The material in a slump moves in one large mass.

iv. Creep:

Creep is a very slow downhill movement of rock and soil. Often a result of freezing and thawing of water in cracked layers of rock beneath the soil. It is so slow that it can hardly notice.

How is water as agent of erosion? [2004, 2006] [2007, 2012]

The following erosions are caused by water:

1. Splash erosion: Raindrops may have sufficient kinetic energy when the fall on soil that the impact can produce detachment and airborne movement of small soil particles.

2. Sheet erosion: Sheet erosion is produced by heavy rain on bare soil where water flows as a sheet down gently sloping land, removing soil particles in thin layers more or less evenly.

3. Runoff: It occurs where precipitation exceeds soil infiltraction rates. Surface runoff turbulence can often cause more erosion than the initial raindrop impact.

4. Rill erosion: It occurs in discrete streamlets carved into the soil. When rills become too deep to be removed by plowing, gullies form.

5. Gully erosion: It results where water flows along a linear depression eroding a trench.

6. Valley or stream erosion: It is produced when water continuously flows along a linear feature, eroding downward, deepening the valley, and extending the valley headward towards the hillside.

How do glaciers cause erosion?

I. A glacier is a large mass of ice and snow moving on land under its own weight.

II. As glaciers pass over land they erode it, changing features on the surface.

III. Glaciers then carry eroded material along and deposit it somewhere else.

IV. There are two types of glaciers:
a. continental and
b. Valley glaciers.

<u>Continental glacier</u>: is a glacier that covers much of a continent or large island.

Today they cover about 10% of earth's land and cover most of Antarctica and Greenland.

These glaciers can flow out in all directions, spreading out like pancake batter in a pan.

<u>A valley glacier</u>:
A valley glacier is a long, narrow glacier that forms when snow and ice build up high in a mountain valley.

The sides of the mountains keep these glaciers from spreading out in all directions. Usually these glacier are smaller than continental glaciers, but can be kilometers long.

How do glaciers shape the land?

I. The movement of a glacier changes the land beneath it.

II. Although glaciers work slowly they are a major source of erosion.

III. The two process by which glaciers erode the land are plucking and abrasion.

IV. As a glaciers flow over the land it picks up the rocks in a process called plucking.

V. Due to the extreme weight of glaciers it can break rocks and then the rocks freeze to the bottom of the rock carrying it with it when it moves.

VI. As rocks remain on the bottom of the glacier and it drags them across the land, abrasion occurs as it scratches the bedrock.

How do waves contribute to erosion?

I. The energy in waves comes from wind and that blows across the water surface.

II. Waves shape the coast through erosion by breaking down rock and transporting sand and other sediment.

III. Waves shape a coast when they deposit sediment, forming coastal features such as beaches.

How does wind contribute to erosion? [2006]

I. Wind by itself is the weakest agent of erosion however it can be a powerful force in shaping the land areas where there are few plants to hold the soil in peace.

II. Wind causes erosion by deflation and abrasion.

III. Deflation is the process where wind blows loose sediment, removing small particles.

IV. The stronger the wind the heavier sediment that can be moved.

v. Abrasion by wind-carried sand can polish rock but causes little erosion.

vi. It was once thought that the sediment carried by wind cut the stone shape, but now more evidence shows that most landforms are the result of weathering and wind erosion.

Some landforms created by erosion:

Sand dunes:

Sand dunes are mounds of sediment drifted by the wind. Dunes can be seen along shore of oceans but are common in desert regions.

Loess: [2004]

Loess are fine, wind blown sediment like silt and clay. Loess help to form fertile soil and create valuable farmlands.

Deserts: [2005, 2008]

A desert is a barren area of land where little precipitation occurs, and consequently living conditions are hostile for plant and animal life. The four types of desert are hot and dry (subtropical), semiarid (cold winter), coastal and cold (polar) desert.

CONSTRUCTION MATERIALS

Dressing of stones : [2002]

Dressing of stones is a process of surfacing and shaping of rocks available naturally. It is the working of quarried stone into the shape and size required for size. The place where the the rocks are abundantly available is called as a quarry. The process of taking stones from the natural bed is known as quarrying.

Different stages involved in stone dressing:

1. Sizing : The irregular quarried rock is cut into desired dimensions by removing extra portions. It is generally done using hammers and chisels on cutting machines.

2. Shaping : Once cut to desired dimensions extra projections are removed to shape the stone.

3. Plaining : It is the process of removing irregularities from the stone surface.

4. Finishing :

It is done by rubbing the stone surface with an abrasive material like Silicon carbide.

5. Polishing :

In this stage the stone is polished by hand on machine to make it more attractive. It is generally done in stones like lime stones, marbles and granite.

Why stone dressing is important ?

The dressing of stone is important so that they are dressed in suitable shapes and polished to give a smooth surface if desired. The stones are used in different types of masonry, therefore it has to be cut and shaped to fit in the type of work needed.

Scree : [2005, 2008]

Scree is a collection of broken rock fragments at the base of crags, mountain cliffs, volcanoes or valley shoulders that has accumulated through periodic rockfall from adjacent cliff faces. Landforms associated with these materials are often called talus deposits. Scree is smaller than talus. Scree is loose and small and talus is larger and not as loose as scree.

Explain the requirements of a stone should fulfill so that it can be suitably used as

1. Concrete aggregate : [2008,2009,2007,2011,2012,2015,2016]

i. It should have good compressive strength.
ii. It should have good binding power with the cementing materials.
iii. It should be capable of breaking into subangular fragment.
iv. It should be free from mineral such as gypsum.

Example: Sandstone.

2. Railway ballast : [2007,2008,2009,2011,2012,2015,2016]

i. It should have high compressive strength.
ii. It should have high modulus of elasticity.
iii. It should be hard and tough enough.
iv. It should be free from cracks, joints etc.
v. It should be capable of breaking into coarse.

Example: Granite, Basalt, Quartz.

3. Rip-rap material: [2010,2011]

i. It should have a good compressive strength.
ii. It should be hard and resistance to abrasion.
iii. It should be free from cracks.

iv. It should be free from soluble mineral constituents.

Example: Granite, Basalt, Sandstone.

4. Roofing material: [2010]

i. Must possess a sufficient degree of fissility to allow rocks to split into thin slabs.

ii. Should be durable.

iii. It should be Impermeable.

Example: Slate

5. Masonry work: [2010]

i. It should be hard.

ii. It should be tough.

iii. It should be free from cracks

iv. It should be free from sand holes.

v. It should be cavity free.

Example: Limestone, sandstone, granite, marble, laterite etc.

LANDSLIDE & LAND SUBSIDENCE

LANDSLIDE

Landslide: [2013]

Downward and outward movement of slope forming materials composed of rocks, soils, artificial fills, or combination of all these materials along surfaces of separation by falling, sliding and flowing either slowly or quickly from one place to another is called landslide.

Landslides are simply defined as down slope movement of rock, debris and/or earth under the influence of gravity.

Types of landslides: [2005, 2007, 2011, 2013, 2016]

a. Based on depth of flow:

1. Surface slide (maximum depth (m), $D_m < 1.5$)
2. Shallow slide (D_m : 1.5-5)
3. Deep slide (D_m : 5-20)
4. Very deep slide (D_m : > 20).

b. Based on type of movement :

1. Falls:

Free falling of detached bodies of bedrock or boulders from a cliff or steep slope. It can be very rapid to extremely rapid movements.

2. Topples :

Topples occur when one or more rock units rotate about their base and collapse.

3. Slides :

Rock slide is a sudden down slope movements of detached masses of bedrock.

i. Rotational slide :

Move along a surface of rupture that is curved and concave.

ii. Translational slide :

Occurs when the failure surface is approximately flat or slightly undulated.

4. Lateral spread :

Occurs when the soil mass spreads laterally and this spreading comes with tensional cracks in the soil mass.

5. Debris flow:
Down sloped movement of collapsed, unconsolidated material typically along a stream channel.

6. Creep:
It occurs mainly in the soil mantle that part of the soil from the surface to a few centimeters or meters below the surface. Creep is imperceptibly slow down slope movement of earth.

Factors cause and trigger landslide: [2010, 2011, 2013, 2016]

A. Natural factors:

1. Gravity:
Gravity works more effectively on steeper slopes.

2. Geological factors:
Geology setting that places permeable sands and gravels above impermeable layers of silt and clay on bedrock.

3. Heavy and prolonged rainfall:
Slides occur often with intense rain by creating zone of weakness, also water tables rise with heavy rain makes some slopes unstable.

4. Earthquake: Ground vibrations created during earthquakes.

5. Waves: Wave action can erode the beach on the toe of a bluff, cutting into the slope and setting the stage for future slides.

6. Volcanoes: Volcanic ash deposits are prone to erosion and subjected to mud flows due to intense rainfall.

7. Fluctuations of water level due to the tidal action.

8. Deposition of loose sediments in delta areas.

B. Anthropogenic factors:

1. Inappropriate drainage system: Surface runoff of irrigated water on slopes exposes soil under cultivation to erosion. Part of this water is absorbed by soil increasing its weight which can put an additional load on the slope.

2. Cutting and deep excavations on slopes for buildings, roads, canals and mining: causes modification of natural slopes, blocking of surface drainage, loading of critical slopes and withdrawal to toe support promoting vulnerability of critical slopes.

3. change in slope/land use pattern, deforestation, agricultural practices on steep slopes: contributed to creep and withdrawal of toe support in many cases.

C. Combination of factors:

For example an earthquake may trigger a landslide which in turn may dam a valley causing upstream flooding and subsequent dam burst. This will lead to flooding in lower catchments areas.

How to minimize landslide hazards?

A. Passive intervention:

i. Choose a safe location to build your home, away from steep slopes and places where landslides have occurred in the past.

ii. Prevent deforestation and vegetation removal.

iii. Avoid weakening the slope.

B. Active preventive intervention:

1. Reforestation: Root systems bind materials together and plants do both prevent water percolation and take water up out of the slope.

ii. Proper water runoff: Proper water runoff must be ensured by providing a proper canalization network.

iii. Drainage: Good ground drainage is essential to prevent saturation and consequent weakening. Drainage is also needed in civil work, like retaining walls.

iv. Proper land use measures: Adopt effective land use regulations and building codes based on scientific research.

v. Structural measures: Nets, retaining walls and major civil works to mitigate landslides.

C. Non structural measures:

i. Awareness generation: Educate the public about signs that a landslide is imminent so that personal safety measures may be taken.

ii. Financial mechanisms: Support the establishment of landslide insurance.

iii. Legal and policy: Legislation to direct a governmental or private program to reduce landslide losses should be strengthened.

D. Landslide hazard mapping and use of GIS:

i. Landslide hazard zonation of the vulnerable areas.

ii. Use of remote sensing and ground truth data for making landslide hazard zone map.

iii. Such maps are used to develop mitigation plans in consultation with experts.

Losses due to landslide :

A. Direct losses :

i. Most damaging impact of landslides is loss of life. It may cause death and injury to people and animals.

ii. It may cause loss of property and assets.

iii. It damage infrastructure as well as life line facilities.

iv. Earth mass can effect water resources in the area by blocking rivers, irrigation channel, diverting water ways reducing storage capacity of tanks, ponds, etc.

v. It may cause loss of agricultural lands.

vi. It may cause loss of places archeological, historical and cultural importance.

B. Indirect loss :

i. Value of immoveable properties will be reduced.

ii. There will be loss of revenue due to loss of productive area and productivity of available area.

iii. It may increase the cost of essential commodities.

iv. Productivity of agricultural land and forest land will be decreased.

v. Water quality will be adversely affected.

vi. It may cause reduction in quality of life.

vii. It affects people's feelings, thought, actions and relationships.

Where landslides do occur? [2016]

1. Landslides are associated with hilly or mountainous landscapes.

ii. They are also common along coastlines and river valleys.

iii. They occur most frequently in regions where climate and precipitation, bedrock and soil conditions and slopes are susceptible to failure.

LAND SUBSIDENCE

Land subsidence:

Land subsidence is a gradual settling or sudden sinking of the earth's surface.

Causes of land subsidence:

i. Excessive load on the ground.

ii. Extraction of oil.

iii. Extraction of water.

iv. Extraction of mining.

v. Presence of swamp ground.

vi. Solution of rocks or soil.

Prevention of land subsidence: [2005, 2011]

i. Compaction can be done if the soft and loose soil is of small thickness and load is not going to be much.

ii. In all types of construction works loading should be kept in accordance with the strength of the ground.

iii. All types of ground cutting work, discharge of water should be taken care of.

iv. In all mining and quarrying works, the open space made should be filled back properly.

v. The extraction of ground water must be in accordance with its replenishment.

vi. The surface drainage should be planed in a very appropriate way so that the water does not accumulate anywhere.

vii. Growing grass and afforestation should be done on bare ground which are prone to land subsidence.

Differences between landslide and land subsidence:

2004, 2006, 2007, 2008, 2009, 2010, 2012, 2015

Landslide	Land subsidence.
Along the sloping surface if the loose and unsupported soil moves downward, this downward movement is known as landslide	The gradual settling or sudden sinking of the earth's surface is known as land subsidence
It occurs along sloping surface.	It occurs in plane land.
It causes due to cut of materials at the toe, earthquake, rain, glaciers excessive load on the top of slope or on the slope.	It causes due to weak soil. excessive load on the ground. extraction of water, oil, mining, swampy ground etc.
It can be prevented by flattening the slope depositing the materials at the slope, vegetation and planting, not allowed load than design load	It can be prevented by compaction. refilling the voids, making the recharge equal to discharge etc.

GEOMORPHOLOGY

INTRODUCTION

Geomorphology:

Geomorphology is the science of land forms. In Greek word Geo means earth, morphe means form and logos means discourse. So geomorphology means study of landforms. Geomorphology is more than a description of the features on land such as mountains, rivers, glaciers or dams.

Uses of knowledge of local geomorphology:

i. For avoiding environmental degradation.

ii. For mitigating natural hazards such as floods and landslides.

iii. For planning cities and roads of the future.

Branches of geomorphology: Different branches of geomorphology are:

1. Process of geomorphology:

Geomorphology in which processes are studied in details is known as process geomorphology.

Different branches of process geomorphology:

i. Fluvial geomorphology: In which process running water is studied in detail is known as fluvial geomorphology.

ii. Glacial geomorphology: In which process glacier is studied in detail is known as glacial geomorphology.

iii. Aeolian geomorphology: In which process wind is studied in detail is known as aeolian geomorphology.

iv. Coastal geomorphology: In which process coastal water is studied in detail is known as coastal geomorphology.

2. Tectonic geomorphology: study of the effect of tectonic movements on landforms is called tectonic geomorphology.

3. Structural geomorphology: study of the effect of geological structure on landforms is called structural geomorphology.

4 Climatic geomorphology:
The study of the dominant influence of climate on landforms is called climatic geomorphology.

5. Applied geomorphology:
Use of the knowledge of geomorphology for flood prevention, environmental impact mitigation etc is called applied geomorphology.

6. Regional geomorphology:
An account of landforms and processes found over a large area is regional geomorphology.

7. Theoretical geomorphology:
Theories that explain how the processes work and how the landforms are formed carry out theoretical geomorphology.

8. River morphology:
Study to describe of river channels and how they change in shape and direction over time is known as river morphology.

River:
River is defined as the concentrated flow of water, formed by the union of several streams. The quanti of water in a river varies

almost from moment to moment. The flow of a river depends upon the duration, the amount of the precipitation and the local hydrological conditions.

Types of river:

I. Ephemeral:
The rivers which carry water only during and immediately after a rain are known as ephemeral river.

II. Non perennial or Intermittent: The rivers which flow during a part of the year e.g. during the wet season of the humid tropics are called non-perinnial or intermittent.

III. Perennial:
The rivers which flow all the year round they are known as perennial.

IV. Peculiarity:
Peculiarity is that the flow may only endure for an hour or two.

V. Endoreic:
Streams with interior flow i.e. mixed with the water surface within the country are known as endoreic.

VI. Exoreic:
The stream with exterior flow i.e. mixed to the sea are called exoreic.

Importance of river morphology:

River is important for its significance to human use. Not only for drinking but river can also be used for irrigation, navigation, fishing, power generation, flootation of timber, recreation etc.

Why river is important in geological study?

1. It is directly responsible in the development of the major landforms of the earth surface.

ii. It is indirectly related to many other geomorphological processes in fluvially dominated landscapes.

iii. It is very useful to human being. Therefore the study of the river is significant in the physical geography.

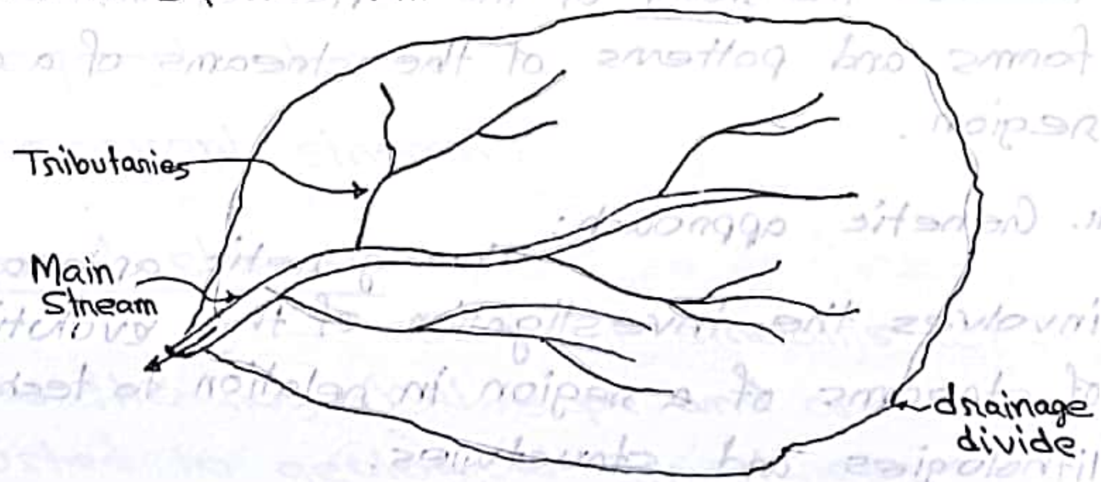
DRAINAGE SYSTEM AND PATTERNS

Drainage basin: [CT-Influence 14, 2006]

The fundamental unit of study for fluvial processes is the drainage basin or watershed.

A drainage basin is a portion of the earth surface that contains a main stream and its tributaries and is bounded by a drainage divide.

The shape and size of the drainage basin can conceivably affect stream discharge. The basin size can vary from a few km^2 to more than a million square km.



Watershed: [2004]

The boundaries of the basin are known as the watershed and will usually be marked by areas of high land.

Drainage area or catchment area: [2005] The entire area that collects the rainwater and contributes it to a particular channel is called the drainage area or catchment area.

Drainage network: The main or trunk stream and its tributary streams that drain the basin area collectively from the drainage network.

The study of the characteristics of drainage network of a particular region is approached in two ways:

1. Descriptive approach: The descriptive approach involves the study of the characteristics of the forms and patterns of the streams of a given region.

ii. Genetic approach: The genetic approach involves the investigation of the evolution of streams of a region in relation to technics, lithologies and structures.

Drainage system:

Drainage systems refer to the origin and development of structures through time.

Factors:

The origin and subsequent evolution of any drainage system in a region are determined and controlled by two main factors.

i. Nature of initial surface and slope

ii. Geological structure.

Classification of drainage system:

Streams of drainage systems are divided in two broad categories. on the basis of the adjustment of the streams to the initial surface and geological structures.

1. Sequent stream

2. Insequent stream.

Sequent stream:

Sequent streams which follow the regional slope and are well adjusted to geological structures. It is classified as the following:

i. consequent stream: [2015]

If the course of streams and rivers are parallel to the direction of surface slope then the streams are called consequent streams.

ii. Obsequent stream :[2015]

If a stream flows in a direction opposite to that of the consequent stream then it is called obsequent stream.

III. Subsequent stream: A stream that follows a line of geologic weakness such as the outcrop of a soft bed, a sequence of major joints, a fault trace on the axis of an anticline. Such a stream tends to extend headwaters actively and may acquire further tributaries through the process of river capture.

IV. Resequent stream or secondary consequent:

If the stream that flows in the direction of the consequent stream but at a level lower than the initial surface then it is called resequent or secondary consequent.

Insequent stream:

Insequent streams which do not follow the regional slope and are not adjusted to geological structures.

It is classified as the followings:

i. Antecedent stream:

An antecedent stream is a stream that maintains its original course and pattern despite the changes in underlying rock topography.

Drainage pattern:

The drainage pattern means the geological form of the drainage systems and the spatial arrangement of streams in particular locality or region.

Classification of drainage pattern:

1. Dendritic pattern: [2008, 2009, 2012, 2014]

i. A dendritic drainage pattern is the most common form and looks like the branching pattern of tree roots.

ii. It is commonly encountered in areas of uniform or comparable lithology and in areas with less prominent regional slope.

iii. A notable characteristics of it is the presence of tributary streams branching in all directions.

iv. A variety of dendritic drainage pattern is the pinnate drainage.

v. Although the tributaries join the main stream at all angles, junction angles considerably less than 90° are prevalent.

2. Trellis pattern:

i. Trellis drainage patterns look similar to their namesake, the common garden trellis.

ii. It is characterized by elongated tributaries following parallel or sub-parallel to the main stream.

iii. The main primary and secondary tributaries join the main stream at right angles.

iv. The trellis drainage is a characteristic of folded mountains.

3. Rectangular pattern:

i. The rectangular drainage pattern is found in regions that have undergone faulting.

ii. A rectangular drainage pattern displays orthogonal bends in both the tributary as well as the parent streams.

iii. This is typically developed in areas underlain by rocks with right angled joints, fractures, lineaments and faults.

iv. Unlike the trellis pattern the rectangular pattern is more regular and the tributes are not necessarily elongated and parallel to the main stream.

4. Angulate pattern:

Angulate pattern is a modified type of rectangular pattern which develops in areas where joints, faults, lineaments do not intersect at right angles.

5. Radial drainage pattern: [2008, 2009, 2010, 2012]

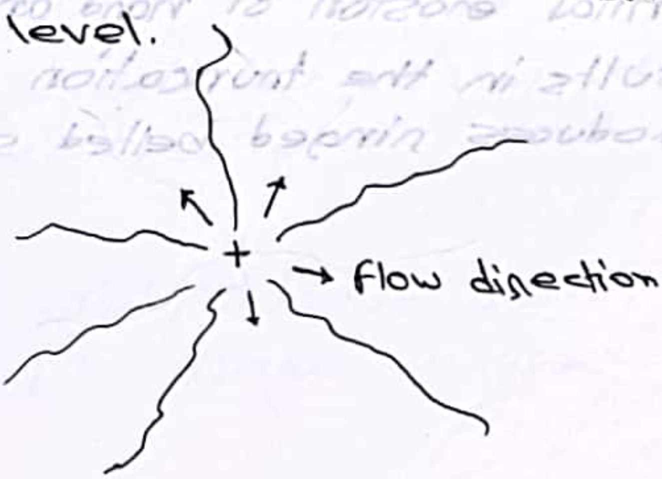
i. The radial drainage pattern or centrifugal pattern develops around a central elevated point.

ii. The streams emerge at the central point of the aforesaid reliefs and drain down the sloped in all directions.

iii. Since the streams follow the slopes and hence they are basically consequent streams.

iv. These streams look like the spokes of a wheel or the radii of a circle.

v. Entire drainage network of Srilanka is an ideal example of radial drainage pattern at macro level.



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6. Centripetal or inland drainage pattern:

i. It is opposite to the radial drainage pattern because it is characterized by the streams which converge at a point which is generally a depression.

ii. This pattern is formed by a series of streams.

iii. The Kathmandu valley of Nepal presents an ideal example of centripetal drainage pattern.

7. Annular drainage pattern:

i. It is also known as circular pattern.

ii. It is formed when the tributaries of the master consequent streams are developed in the form of a circle.

iii. It is developed over a mature and dissected dome mountain.

iv. Differential erosion of hard and soft rock beds results in the truncation of the beds which produces ringed belted structure.

8. Pinnate drainage pattern:

i. A variety of dendritic drainage pattern is pinnate drainage pattern.

ii. This pattern resembles the veins of a leaf.

iii. It is developed in a narrow valley flanked by steep ranges.

iv. The drainage network of upper son and Narmada rivers denote the example of it.

9. Barbed drainage pattern:

i. It is usually observed in the headwaters and is limited in extent.

ii. Often it indicates control of geological structure.

iii. The tributaries join their master streams in a hook-shaped bend.

iv. It is generally developed due to river capture.

10. Herringbone pattern:

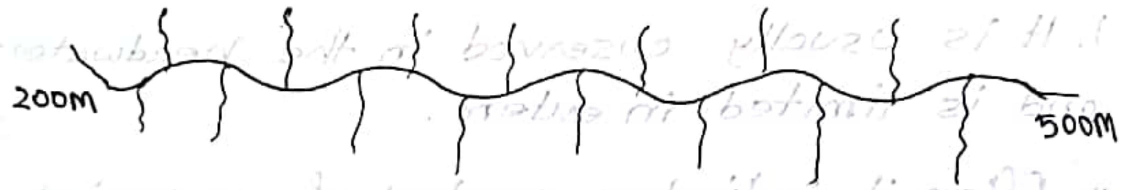
I. It is also known as rib pattern.

II. It looks like the rib bones of human being

III. It is developed in mountanous areas where broad valleys are flanked by parallel ridges having steep hill side slope.

IV. The course of the tributaries are straightened because of slope factor and little distance between the ridges and longitudinal consequent.

V. The term herringbone has been derived from the pattern of bones of herring fish.



11. Parallel drainage pattern: [2010]

I. Parallel drainage pattern comprises numerous rivers which are parallel to each other and follow the regional slope.

II. It is more frequently developed on uniformly slopping and dipping rock beds.

III. It may be pointed out that a sub-parallel pattern is therefore essentially an initial drainage pattern.

IV. The western coastal plains of India represent several examples of parallel drainage pattern.

12. Irregular pattern:

i. It does not reveal any systematic arrangement or design of the main and tributary streams.

ii. This pattern is observed in regions that have recently experienced retreat of ice.

iii. The existing drainage is very different from that which preceded the last ice invasion.

The location, number and flow directions of different streams of a particular region depends on:

i. Nature of slope

ii. structural control.

iii. Lithological characteristics

iv. Tectonic factors.

v. Climatic conditions.

vi. vegetal characteristics.

Discuss the different phases of drainage network development .[2009, 2011, 2012, 2014, 2016]

In 1931 Glock proposed a model of drainage network development. There are five phases of drainage network development. They are described below:

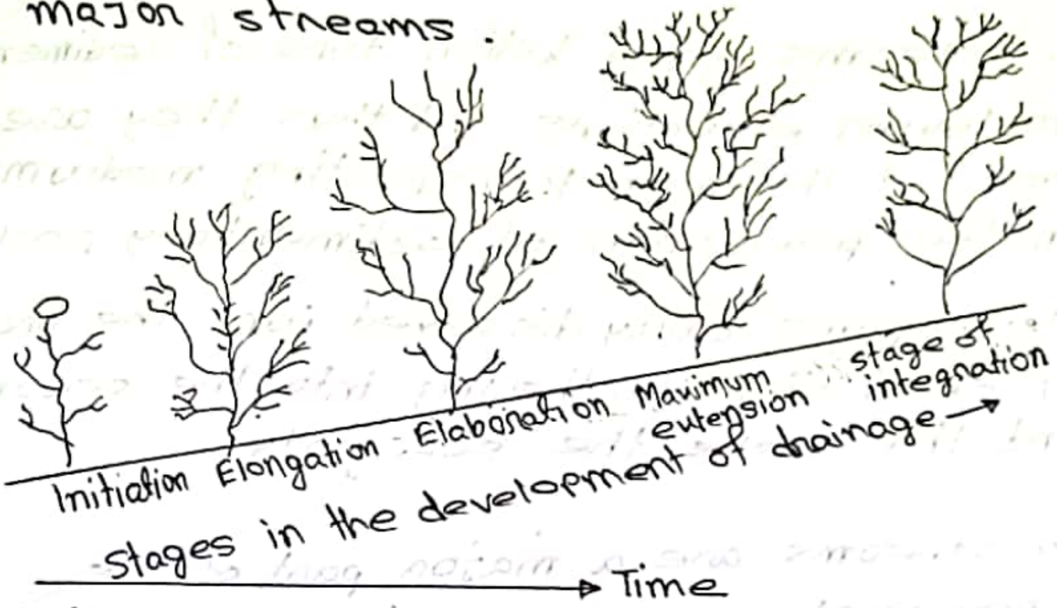
1. Initiation:
In initiation phase a skeleton drainage network is established on an undissected plain. The number of main streams is small and the inter stream area is large.

2. Elongation:
In this phase all the major streams are extended by headwater erosion. The number of tributary streams and the average stream length increases.

3. Elaboration:
In this phase the small streams multiply rapidly. The network spreads, invades undissected interfluves and drainage density increases.

4. Maximum extension:
Further development leads to the phase of maximum extension. This is the stage of fully developed network.

5. Stage of integration: The final phase of drainage network development is the stage of integration. During this phase the number of smaller streams decreases to minimum and the landscape is dominated by major streams.



Stages in the development of drainage →

River:

A river is a natural flowing water course which carries water along with sediment towards the ocean.

Stream:

A stream is a body of water that carries rock particles and dissolved ions and flows down slopes along a defined clearly path, called a channel. Streams may vary in width from a few centimeters to several kilometers.

A river and a stream are both fast moving bodies of water. but a river is called a river because it is larger, deeper and longer than a strem. Another difference is that a stream is a small flowing water.

Why streams are important? [CT- Influence 14, 2014, 2016]

Streams are important for several reasons:

i. Streams carry most of the water that goes from the land to the sea and thus they are important part of the water cycle.

ii. Streams carry billion tons of sediment to lower elevations and thus they are one of the main transporting mediums in the production of sedimentary rocks.

iii. Streams carry dissolved ions, the products of chemical weathering into the oceans and thus make the sea salty.

iv. Streams are a major part of the erosional process, working in construction with weathering and mass wasting. Much of the surface landscape is controlled by stream erosion, evident to anyone looking out of an airplane window.

v. Streams are a major source of water and transportation for the world's human population. Most population centers are located next to streams.

Types of rivers:

River reaches can be divided according to topography of the river basins as

1. Upper reaches
2. Middle reaches
3. lower reaches of rivers.

Upper reaches of rivers:

The upper reaches comprise of the hilly and submontane region.

i. Hilly reached incised rivers:

This type of river is generally formed by the process of degradation.

The sediment which it transports is often dissimilar in character to that of the river bed. Since most of it comes from the catchment due to denudation and soil erosion.

ii. Foothill submontane reach - boulder rivers:

These are characterized by the steepness of their slopes and their beds consist of a mixture of boulders, gravel, shingle and sand.

When the rivers descend from the steep region into the foothill area, the slope suddenly flattens resulting in considerable reduction in sediment transporting capacity. The sediment accordingly deposits forming an alluvial fan.

Middle reaches river: The middle reach is formed by flood plain. Rivers in flood plain is also kwon as alluvial rivers.

It is further classified as :

i. Aggrading or accreting river: [2010, 2015, 2016]
If a river is building up its bed then it is called an aggrading river or accreting river.

A river builds up its bed because of.

a. heavy load

b. Obstruction like a barrage or dam across it raising the water level and flattening the slope.

c. Extension of delta at the river mouth.

d. Sudden instrusion of sediment from a tributary!!

ii. Degrading river: [2007, 2010]
If a river bed is getting scoured from year to year then it is called degrading river.
This type of river is found below the dam or barrage.

iii. Stable river:

When a river carries down sediment which it receives without either depositing the material or scouring the bed it is called a stable river.

Lower reach river:

The lower reach or end reach covers the tidal portion and the delta region.

1. Tidal river:

If a river goes through periodic changes in water level due to tides it is called tidal river.

ii. Delta river:

A river may split into branches and form a delta in the last journey to the sea. The last portion is called delta river.

Other types:

River can also be classified according to the stage and nature of flood hydrographs.

1. Flashy river: [2014]

A river is called flashy if the rise and fall of its floods are sudden.

In the case of flashy rivers the flood hydrographs are steep indicating thereby that the flood flow occurs all of a sudden. The flood rises and falls in a very short period of a day or two.

II. Virgin river:

In arid zones a river may completely dry up before joining another river or sea. Such a river is called a virgin river.

Waters in rivers of this type disappear due to high percolation.

Evaporation losses after flowing certain distance from their source.

III. Himalayan river:

Rivers derived their waters from melting snow during the spring and summer and also from rains during the monsoon. These rivers are more or less perennial and they can give dependable yields in the summer as well as in the monsoon.

The Himalayan rivers carry heavy sediment loads because of the soft friable Himalayan rock.

IV. Non Himalayan river:

Non Himalayan rivers get their supplies chiefly during the monsoon. they dry up practically in the summer. Originating from the mountains the rivers run in all directions.

Perennial streams:

Perennial streams are those that carry water through out the year. Most large rivers from the Himalayas are examples of perennial streams.

Seasonal streams:

Seasonal streams are those that flow for a part of the year. streams are common in seasonally wet areas are the seasonal streams.

Ephemeral streams:

Some streams flow only in direct response to rainfall and carry water only during and immediately after heavy rains. These are ephemeral streams.

Allochthonous rivers: [CT- InfluenCE-14]

Rivers that originate in high rainfall region but flow through dry regions for much of their course. are classified as allochthonous rivers. such as Nile, the Colorado, the Indus etc.

River capture or stream piracy: [2009, 2011, 2012, 2013, 2005]

The diversion of the part of the course of a river by another river is called stream diversion, river capture or stream capture or stream piracy.

River capture is a natural process which is more active in the youthful stage of the valley development.

Capturing of captor stream: The river which captures the course of another river is called the capturing of captor stream.

Captured stream: The part of the stream which has been divested of its course and water is called captured stream.

Evidence of river capture: There are four major evidence of river capture.

i. Elbow of capture: It denotes the point where the course of the captured stream has been diverted to the course of the captor stream.

ii. Cols or wind gaps: It is the dry portion of the beheaded stream just below the elbow of capture.

iii. Water gaps: The water gaps denote the deep and narrow valley in the form of a gorge formed by the captor stream through headward erosion across the ridge.

iv. Misfit or underfit stream: It is the lower course of the captured stream. It is called misfit because of the fact that the former valley of the captured stream becomes too large and wide for the beheaded stream because of substantial decrease in the volume of water due to diversion of its water to the captor stream.

The conditions on which river capture occurs. [2008, 2009, 2011, 2012, 2013, 2014

River captur occurs under the following conditions:

1. Steep channel gradient.

ii. Relatively narrow valley so that water may not spread in the otherwise wide and flat valleys.

iii. Higher volume of water so that the velocity and discharge may be sufficiently high.

iv. Soft rocks so that the river may resort to rapid rate of headwater erosion.

v. Deeper valley than the valleys of other neighbouring rivers.

vi. Low sediment load so that the river may resort to active erosion etc.

THE MORPHOMETRIC ANALYSIS OF DRAINAGE

Morphometry:

The word 'morpho' means form and 'metry' means measurement. So the word morphometry means measurement of form.

Therefore the techniques related to the form measurements in geomorphology include a wide scope of measurement techniques of a large number of variables of spatial pattern and forms of the landforms i.e. the shape, size, relief, linear network and characteristics of drainage measured through different parameters to bring about weighage of the different aspects of the landforms.

Basin morphometry:

The basin morphometry includes the analysis of the characteristics of linear, areal and relief aspects of fluvially originated drainage basin.

Linear aspects of the basin:

The linear aspect includes the discussion and analysis of

i. Stream order (μ)

ii. Stream number (N_μ)

iii. Bifurcation ratio (R_b)
iv. Stream lengths (L_u)
v. Length ratio (R_L)
vi. Length of overland flow (L_g)
vii. Sinuosity index etc.

<u>Stream ordering</u>:

Stream ordering refers to the determination of the hierarchical position of a stream within a drainage basin.

Different stream ordering methods are –

i. Gravelius' Scheme of stream ordering
ii. Horton's Scheme of stream ordering
iii. Strahler's Scheme of strem ordering.
iv. Shreve's stream-link ordering method.

It is the first step of quantitative analysis of the watershed.

<u>Horton's Scheme of stream ordering or Orders of stream channel suggested by Horton with sketches.</u> [2006, 2016]

According to Horton ordering of stream the 'finger-tip' tributaries which do not have their own feeders are designated as 1st order streams. When two streams of 1st order are joined together they form 2nd order stream. just below their junction. Similarly when two streams of 2nd order are joined together they form 3rd order stream. and this process continues till the trunk stream is given the highest order.

According to Horton's scheme when two streams of same order meet they form the next higher order and each stream can recieve tributaries of lower order than its own order. If a stream or streams of lower order join a stream of higher order, the order of recieving stream do not increase.

After all the streams of a drainage basin are classified in the 1st round they are reclassified in order to determine the headward extension of the streams of different orders except the 1st order stream.

Limitations of Hortons scheme of stream ordering.

1. Horton's Scheme of ordering is difficult, tedious and time consuming as it involves classification and reclassification of streams several times.

11. Some of the fingertip tributaries are given orders higher than one while other fingertip tributaries of the 1st order, with the same magnitude are not upgraded.

Horton's stream laws :

Different laws of drainage composition like law of stream number, length ratio and law of stream length, law of stream slope and sinuosity indices are known as Horton's stream law.

a) Horton's law of stream number :

Horton's law of stream numbers states that the number of stream segments of successively lower orders in a given basin tend to form a geometric series beginning with the single segment of the highest order and increasing according to constant bifurcation ratio.

The law of stream numbers is expressed in the following form of negative exponential function model

$$N_\mu = R_b^{(k-\mu)}$$

where,

N_μ = Number of stream segments of a given order.

R_b = constant bifurcation ratio

μ = basin order

k = highest order of the basin.

The total of order wise stream segments is known as stream number.

Bifurcation ratio [2014]

Bifurcation ratio is related to the branching pattern of the drainage network. It is defined as the ratio of the number of streams of a given order (N_μ) to the number of streams of the next higher order ($N_{\mu+1}$). It is expressed as the following equation

$$R_b = \frac{N_\mu}{N_{\mu+1}}$$

where, N_μ = Number of streams of a given order.

$N_{\mu+1}$ = Number of streams of the next higher order.

Bifurcation ratio is a dimensionless property of the drainage basin is supposed to be controlled by drainage density, stream entrance angles, lithological characteristics, basin shapes, basin area etc.

Horton further worked out the following equation to find out the total number of the stream segments of the whole drainage basin

$$\sum N_{\mu} = \frac{R_b^K - 1}{R_b - 1}$$

Where, k = highest order of the basin
R_b = constant bifurcation ratio.

Problem: Find out the total number of stream segments in a 5th order drainage basin whose bifurcation ratio is 4. [2009, 2010, 2011, 2012

Solution:
Given, Bifurcation ratio, $R_b = 4$
Highest order of the basin, $K = 5$

∴ Total number of stream segments

$$\sum N_{\mu} = \frac{R_b^K - 1}{R_b - 1}$$

$$= \frac{(4)^5 - 1}{4 - 1}$$

$$= \frac{1024 - 1}{3}$$

$$= \frac{1023}{3}$$

$$= 341$$ Ans

Relationship between stream length and basin order:

I. Total stream length of given order is inversely related to stream order.

II. There is positive relationship between mean stream length and basin order.

III. The cumulative mean lengths of stream segments of successive higher orders increase in geometrical progression starting with the mean length of the 1st order segments with constant length ratio.

Horton's law of stream slope:

It states that the mean slopes of stream segments of successively higher orders in a given basin tend to form a geometric series decreasing according to a constant slope ratio.

The slopes of the streams can be measured from the vertical interval (V.I) and corresponding horizontal interval (H.I) from the contours and length of the stream segments with the help of a rotameter from the contour maps.

The relationship of order and slope may be expressed as:

$$R_s = \frac{S_u}{S_{u-1}}$$

Where S_u is the mean slope of the stream

Length ratio:

The proportion of increase of mean length of stream segments of two successive basin order is defined as length ratio (R_L).

It is calculated according to the following equation

$$R_L = \frac{\bar{L}_\mu}{L_{\mu-1}}$$ [Next lower order (μ-1)]

where, $\bar{L}_\mu = \frac{\Sigma L_\mu}{N_\mu}$ = mean length of all stream segments of a given order(μ).

ΣL_μ = sum of lengths of all stream segments of a given order

N_μ = Number of stream segments of a given order.

Horton's law of stream length:

It states that the cumulative mean lengths of stream segments of successive higher orders increase in geometrical progression starting with the mean length of the 1st order segments with constant length ratio.

The following positive exponential function model of stream length has been suggested

$$\bar{L}_\mu = \bar{L}_1 R_L^{(\mu-1)}$$

Where, $\bar{L}_\mu$ = mean length of the 1st order

R_L = constant length ratio.

stream order under consideration. Therefore the R_s may be worked out successively for the second and the first orders and so on.

For any drainage system the mean R_s may be worked out from

$$R_{s(mean)} = \frac{\Sigma R_s}{N-1}$$

where N is the number of the stream orders.

When the slope ratio (varies 0.3 to 0.6) is know the slope of any stream segment can be worked out as follows

$$S_u = S_1 R_s^{(u-1)}$$

Sinuosity index: The sinuosity of a stream denotes the degree of deviation of its actual path from expected theoretical straight path.

A few models have been developed for the calculation of sinuosity indices as:

S.A. Schumm's model (1963):

$$\text{channel sinuosity} = \frac{O_L}{E_L}$$

where, O_L = observed path of a stream

E_L = Expected path of a stream.

J.E. Muller's model:

channel index $CI = \frac{CL}{AL}$

Valley index, $VI = \frac{VL}{AL}$

standard sinuosity index, $SSI = \frac{CL}{VL}$

Hydrological sinuosity index, HSI = % equivalent of $\frac{CI - VI}{CI - 1}$

Topographic sinuosity index, TSI = % equivalent of $\frac{VI - 1}{CI - 1}$

Where,
CL = channel length
VL = valley length
AL = Air length i.e. shortest distance between the source and mouth of the river.

If SSI = 1 then straight river course
SSI = 1-1.5 then river in sinuous shape
SSI > 1.5 then a meandering course.

Length of overland flow (L_g): Horton used this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. It is equal to the half the reciprocal of the drainage density.

Therefore, $L_g = \frac{1}{2} * \frac{1}{D_d}$

$$= \frac{1}{2} * \frac{1}{\frac{L_k}{A_k}}$$

$$= \frac{A_k}{2L_k}$$

where, D_d = drainage density

A_k = total area of the basin

L_k = total lengths of all stream segments of a basin.

Areal aspects of the basin:

Basin area is very important morphometric attribute as it is related to the spatial distribution of a number of significant attributes such as :

i. Drainage density
ii. Stream frequency
iii. Drainage texture
iv. slope
v. absolute and relative reliefs.
vi. dissection index etc.

That is why H.W. Anderson (1957) has termed it as a devil's own variable because almost every watershed characteristics is correlated with area.

The areal aspects of the drainage basin include the study of

i. Basin perimeter
ii. Basin shape
iii. Law of basin area
iv. Law of allometric growth
v. Stream frequency
vi. Drainage density
vii. Drainage texture etc.

Basin area(A):

Basin area is the area of cumulative from the 1st order to the successive higher order and the trunk stream (master stream) of the highest order represents the total area of the whole basin.

Basin perimeter (P):

Basin perimeter is the outer boundary of the watershed that enclosed its area. It is measured along the divides between watershed and may be used as an indicator of watershed size and shape.

Relative perimeter, $P_r = \frac{A}{P}$

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Basin shape :

The geometry of basin shape is of paramount significance as it helps in the description and comparison of different forms of the drainage basins and it is also related to the functioning of the units of the basins and its genesis.

The ideal drainage basin is usually of pear shape. Various methods have been suggested to calculate the shapes of the basins. On the average three sub-categories of basin shapes have been recognized i.e. i. circular

ii. elongated

iii. Indented.

Different popular methods of computation of basin shape are as follows:

1. Horton's form factor (F) (1932) :

According to Horton form factor may be defined as the ratio of basin area to squar of the basin length.

Form factor $F = \frac{A}{L^2}$

where, A = area of the basin

L = Length of the basin (axial length)

Form factor indicating elongation of the basin shape

The value of F varies from 0 (highly elongated watershed) to the 0.754 (for a perfectly circular watershed)

Thus the higher the value of F, the more circular shape of the basin.

2. Stoddart's (1965) Elipticity index (E):

$$E = \frac{\pi L^2}{4A}$$

The value of E varies from 1 to 0.
It is inversely proportional to form factor.

3. V.C. Miller's Circularity Index (C) (1953):

Circularity index is defined as the ratio of area of basin to the area of the circle with same perimeter as the basin.

$$C = \frac{\text{Area of the basin}}{\text{Area of the circle with same perimeter as the basin}}$$

$$= \frac{A}{P^2/4\pi}$$

$$= \frac{4\pi A}{P^2}$$

where, P is the basin perimeter
A is the basin area.

The value of C varies from 0 (a line) to 1 (a circle).
The higher the value of C the more the circular shape of the basin and vice-versa.

4. S.A. Schumm's (1956) Elongation ratio (R):

Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length.

$$R = \frac{\text{Diameter of circle with same area as basin}}{\text{Basin length}}$$

$$= \frac{D}{L}$$

$$= \frac{\sqrt{4A/\pi}}{L}$$

$$= \frac{2}{\sqrt{\pi}} \sqrt{\frac{A}{L^2}}$$

$$\therefore R = \frac{2}{\sqrt{\pi}} \sqrt{F} \Rightarrow R \propto \sqrt{F}$$

Schumm's R is directly proportional to the square root of Horton's F.

The value of R varies 0 (highly elongated watershed) to 1 (perfectly circular shape).

Thus the higher value of R, the more circular shape of the basin and vice versa.

Area ratio (R_a):

Area ratio denotes proportion of increase of main basin areas between two successive orders and can be calculated by the following equation suggested by A.N. Strahler (1960).

$$R_a = \frac{\bar{A}_\mu}{A_{\mu-1}}$$

where $\bar{A}_\mu$ is the mean area of a given order of the basin.

and $$\bar{A}_\mu = \frac{\Sigma A_\mu}{N_\mu}$$

where N_μ = Number of all segments of a given order

ΣA_μ = Total area of all stream segments of the stream order.

Since the area becomes cumulative with increasing orders and hence area ratios decrease with increasing orders within the basin.

Law of basin area:

A.N. Strahler (1969) postulated that the main basin areas of successive higher stream orders tend to form geometric series beginning with mean area of the 1st order basin and increasing according to constant area ratio. and suggested the following equation of the law of basin area.

$$\bar{A}_\mu = \bar{A}_1 R_a^{(\mu-1)}$$

where $\bar{A}_1$ is the mean area of the 1st order.

R_a is the constant area ratio.

Stream frequency (SF):

Stream frequency on drainage frequency is the measure of number of streams per unit area.

$$SF = \frac{N_\mu}{A}$$

Where N_μ = number of stream.

A = area of basin.

For the computation of stream frequency the basin is conveniently divided into grid squares [more commonly $(mile)^2$ or km^2] depending on the map scale and aerial coverage of the basin and the number of streams in each grid is counted, tabulated and quantified.

The data of stream frequency are classified into certain categories depending upon the nature of data.

Drainage density (Dd): [illegible]

Drainage density refers to total stream lengths per unit area.

R.E. Horton (1945) defined drainage density as a ratio of total length of all stream segments in a given drainage basin to the total area of that basin.

$$D_d = \frac{L_k}{A_k}$$

where, L_k = total length of all stream segments of a basin.

A_k = total area of the basin.

The simplest way to calculate drainage density on a regional scale is to divide the basin into grid squares as one km^2 or $mile^2$ each and to measure the total stream lengths in each grid square and to group the derived data into drainage density categories viz.

i. Very low Dd
ii. Low Dd
iii. Moderate Dd
iv. High Dd
v. Very high Dd.

Difference between drainage density and drainage frequency : [2007, 2017, 2013]

Drainage density	Drainage frequency
Drainage density is the total stream lengths per unit area	Drainage frequency is the measure of number of streams per unit area.
High drainage density is the resultant of weak or impermeable sub-surface material, sparse vegetation	High frequency of stream is found in the areas of non porous bedrocks, relatively high degree of slope, high rainfall and thin vegetation cover
High drainage density is represented by metamorphic, whereas sedimentary exhibits low drainage values.	The high value of drainage frequency represented by mature basins whereas low range indicates the youth stage of development.

Drainage Texture (Dt) :

According to G.H Smith (1950) Drainage texture is an important geomorphic concept by which the relative spacing of drainage lines can be meant.

According to Savindra sing drainage texture refers to relative spacing of streams per unit length in grid squares (km^2 / $mile^2$).

The derivation of drainage texture is quick and easier method as it involves only the counting of stream crossings along the four edges of each grid and its two diagonals rather than measuring the lengths as is done in drainage density.

The following equation is suggested by Savindra singh (1981):

$$D_t = AS = \frac{1}{(t+P)/2}$$

where,

AS = average spacing between two streams.

$$t = \frac{(t_1+t_2)/2}{\sqrt{2}}$$

t_1, t_2 = number of intersections between the stream network and grid square diagonals.

$$P = \frac{P_1+P_2+P_3+P_4}{4}$$

P_1 to P_4 = number of intersections between the stream network and grid square edges.

I. $D_t > 0.8 \rightarrow$ very coarse

II. $D_t \rightarrow (0.8-0.6) \rightarrow$ coarse

III. $0.4 < D_t < 0.6 \rightarrow$ moderate

IV. $0.2 < D_t < 0.4 \rightarrow$ fine

V. $0.001 < D_t < 0.2 \rightarrow$ very fine

Compactness coefficient (C_c):

According to Gravelis (1914) compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area which equals the area of the watershed.

$$C_c = \frac{\text{Perimeter of basin}}{\text{Circumference of circular area that is same as basin area}}$$

$$= \frac{P}{2\pi r}$$

$$= \frac{P}{2\pi \times \sqrt{A/\pi}}$$

$$= \frac{1}{2\sqrt{\pi}} \frac{P}{\sqrt{A}}$$

where, P = perimeter of basin

A = area of basin.

The C_c is independent of size of watershed and dependent only on the slope.

Fitness ratio (R_f):

According to Melton (1957) the ratio of main channel length to the length of the watershed perimeter is fitness ratio which is measure of topographic fitness.

$$R_f = \frac{CL}{P}$$

where CL = main channel length.

P = perimeter of basin.

Wandering ratio (Rw): According to Smart and Surkan (1967) wandering ratio is defined as the ratio of the mainstream length to the valley length.

$$R_w = \frac{CL}{VL}$$

Drainage intensity (Di): Faniran (1968) defines the drainage intensity as the ratio of the stream frequency to the drainage density.

$$D_i = \frac{SF}{D_d}.$$

Infiltration number (IF): The infiltration number of a watershed is defined as the product of drainage density and stream frequency.

$$IF = SF \times D_d.$$

It gives an idea about the infiltration characteristics of the watershed.

The higher the IF, the lower will be the infiltration and the higher run off.

Total relief of river basin(H) Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin.

Here, $H = Z_1 - Z_2$

Relief ratio (R_R): The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line.

$$R_R = \frac{H}{L_B}$$

where, Total basin relief = H

Basin length = L_B

Relative relief (R): The maximum basin relief was obtained from the highest point of the watershed perimeter to the mouth of the stream.

According to Melton's (1957):

$$\text{Relative relief ratio} = \frac{H}{P} \times 100$$

where, P = perimeter

Ruggedness number (Rn): Strahler's (1968) ruggedness number is the product of the basin relief and the drainage density and usually combines slope steepness with its length.

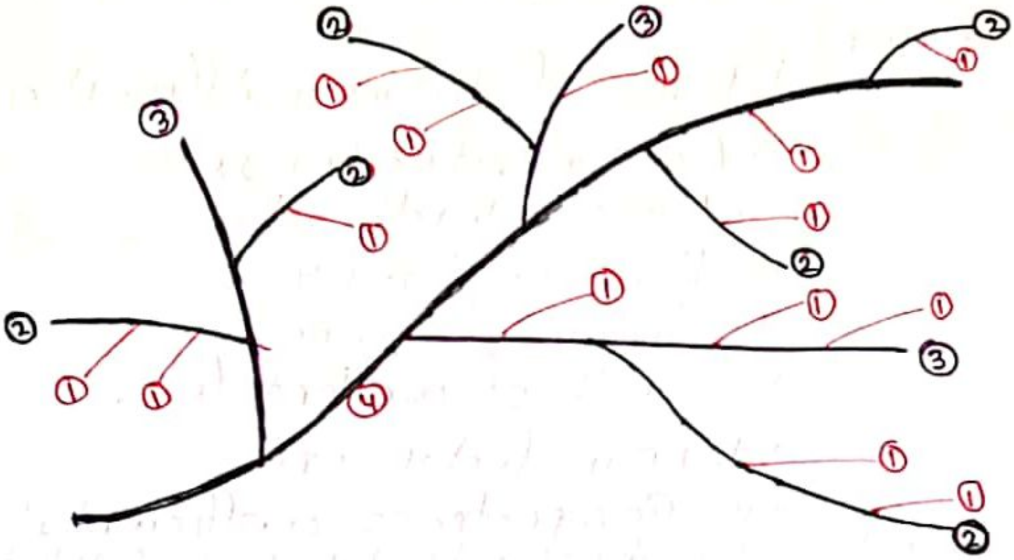
$$R_n = \frac{D_d \times H}{1000} \quad \text{where } H \text{ in meter.}$$

Gradient ratio (Rg): Gradient ratio is an indicator of channel slope which enables assessment of the runoff volume.

$$R_g = \frac{H}{L_B}$$

Problem: Determine A.B.R and A.L.R from the following figure.

Each stream length	1st order	2nd order	3rd order	4th order
	200m	4 km	12km	120 km



Solution:

For the stream network shown above:

Stream order	No. of stream, N_μ	Length of stream L_u	B.R $= \frac{N_\mu}{N_{\mu+1}}$	A.B.R.	L. R $= \frac{L_u}{L_{u-1}}$	A.L.R.
1	14	0.2	$\frac{14}{6} = 2.33$	$\frac{2.33+2+3}{3}$ $= 2.44$	$\frac{4}{0.2} = 20$	$\frac{20+3+10}{3}$ $= 11$
2	6	4	$\frac{6}{3} = 2$		$\frac{12}{4} = 3$	
3	3	12	$\frac{3}{1} = 3$		$\frac{120}{12} = 10$	
4	1	120				

Problem : A drainage area (427.92 square miles) of rectangular shape is given in the figure below. The length of 1st to 5th order streams are 53 miles, 24.8 miles, 70.2 miles, 200.5 miles, and 525.4 miles respectively.

Determine

i. Number of streams in different order.

ii. Average bifurcation ratio

iii. Average length ratio

iv. Drainage density

v. stream frequency

vi. Length of overland flow.

vii. Form factor and

viii. Compactness coefficient if the axial length of the drainage basin is 222.53 miles.

Solution: Using Horton's method:

① Number of streams in differents order:

1st order = 22

2nd order = 7

3rd order = 5

4th order = 2

5th order = 1

(ii) Average Bifurcation ratio $= \frac{1}{4}\left(\frac{N_1}{N_2} + \frac{N_2}{N_3} + \frac{N_3}{N_4} + \frac{N_4}{N_5}\right)$

$= \frac{1}{4}\left(\frac{22}{7} + \frac{7}{5} + \frac{5}{2} + \frac{2}{1}\right)$

$= 2.26$

(iii) Average length ratio $= \frac{1}{4}\left[\frac{L_2}{L_1} + \frac{L_3}{L_2} + \frac{L_4}{L_3} + \frac{L_5}{L_4}\right)$

$= \frac{1}{4}\left[\frac{24.8}{53} + \frac{70.2}{24.8} + \frac{200.5}{70.2} + \frac{525.4}{200.5}\right]$

$= 2.194$

(iv) Drainage density $= \frac{\text{Total length of all the streams}}{\text{Total area}}$

$= \frac{L_1N_1 + L_2N_2 + L_3N_3 + L_4N_4 + L_5N_5}{A}$

$= \frac{53\times22 + 24.8\times7 + 70.2\times5 + 200.5\times2 + 525.4\times1}{42792}$

$= 0.0612$ miles/sq.mile

(v) stream frequency $= \frac{\text{Number of streams}}{\text{total area}}$

$= \frac{22+7+5+2+1}{42792}$

$= 8.646 \times 10^{-4}$

(vi) length of overland flow $= \frac{1}{2} \times \frac{1}{\text{Drainage density}}$

$= \frac{1}{2} \times \frac{1}{0.0612}$

$= 8.17$ mile.

(vii) Form factor = $\frac{\text{Area of the basin}}{(\text{Axial length of the basin})^2}$

$$= \frac{42792}{(222.53)^2}$$

$$= 0.864$$

(viii) compactness coefficient

$$C_c = \frac{\text{Perimeter of basin}}{2\sqrt{\pi A}}$$

$$= \frac{2(L+B)}{2\sqrt{\pi A}}$$

$$= \frac{L + (A/L)}{\sqrt{\pi A}}$$

$$= \frac{222.53 + \left(\frac{42792}{222.53}\right)}{\sqrt{\pi \times 42792}}$$

$$= \frac{222.53 + 192.30}{\sqrt{42792\pi}}$$

$$= 1.13$$

RIVER VALLEYS, GRADED CURVE AND PROFILE OF EQUILIBRIUM

River valley:

A river valley is an elongated depression between hill or mountain ranges occupied and developed by a river. Large rivers create large valleys and small rivers create small valleys.

River valley development:

River valley development takes place in three ways:

i. Valley lengthening
ii. Valley deepening
iii. Valley widening

Process of river lengthening: [2009, 2011, 2012, 2013

1. Head erosion:

A stream begins to cutback. This increases the area of the stream where it diverts towards itself the water of springs, rills etc. This activity is called head erosion. This head erosion work continues till a hard rock intervenes. Sometimes the decrease of slope also stops head erosion. The tributaries of rivers on the opposite slope may reduce the work of head erosion of the river of this side of a divide. Head erosion increases the length of a stream.

2. River meandering: It increases the length of a river. A stream creates many meanders in its course by erosion or deposition of sediment at various places. This makes the river flow in a zig-zag course. This is known as river meandering. It also increases the length of the stream.

3. Mouth expansion: A stream deposits sediment at its mouth where it meets the sea. It makes the mouth extend towards the sea. —

Factors on which valley deepening depends on : [2008, 2010

1. Steep slope: Due to steeper slope the flow of a river increases resulting in the deepening of its channel.

2. Hard rocks and dry climate:
If the rocks around its course are hard and the climate is dry the deepening of valley takes place slowly.

3. Rise of river course:
If endogenetic forces raise the course of stream slowly the river valley deepens.

4. Rolling of rock fragments:
valley is also deepened on account of the rolling of rock fragments on its floor.

5. Mechanical friction:
Water in the river with its fast flow deepens the valley by mechanical friction.

6. Solution action:
Valley is deepened by solution action.

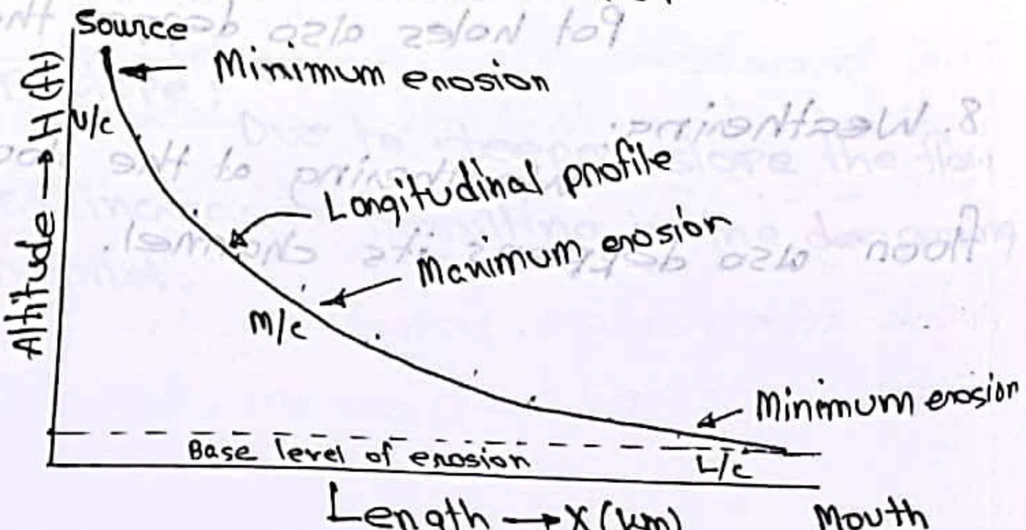
7. Pot holes:
Pot holes also deepen the valley

8. Weathering:
Weathering at the floor of the floor also deepens its channel.

Graded curve and profile of equilibrium:

Grade means continuous curve of descent of a stream floor downstream which has such a gradient throughout longitudinal course of the stream that it can transport all the loads downstream. The river having attained such condition is called graded river and its curve as a graded curve.

When a river develops such a course that channel gradient is such that resultant flow velocity is able to transport entire load, the resultant longitudinal curve of valley thalweg is called graded curve and the river after attaining graded curve is called graded river and the long profile of the river becomes profile of equilibrium as there is balance between transporting capacity of the river and total load to be transported i.e. balance between available energy and work to be done.



Factors controlling equilibrium of the stream:

1. Stream discharge (Q): usually measured in ft^3/sec or m^3/sec. Dependent mainly on climate. The relationship $Q = AV_m$ is very important. Where V_m is the mean velocity of the section and A is the area of section perpendicular to the direction of flow.

2. Sediment discharge and the size of sediment: climate, weathering and all processes delivering sediment to the stream determine the quantity of sediment discharge (tons/day) and the size of sediment. The size of grains and the structure of the original rock material are also important criterion.

3. Slope: The slope adjusts automatically to provide the velocity necessary for transporting the amount and size of the material being delivered to the stream. If the slope is too low for transporting the sediment load, deposition occurs until the slope is sufficient for transporting. If the slope is too steep that it provides a velocity

greater than that necessary to transport the load, erosion reduces the slope. This new slope will provide the velocity needed to transport the sediment load.

Channel slope is important in determining stream velocity and so sediment transport. Generally as the channel becomes narrow so sediment transport becomes more efficient. When narrowing of a channel occurs because of deposition on the bank, erosion of bed is likely to result. Again when the deposition of the channel bed occurs the erosive forces on the bank increases widening of the stream.

4. Channel shape: The ratio of width to depth is used to describe the channel shape. The interaction of discharge, amount of sediment, slope and local factors such as bank erodability and channel alignment determine channel shape.

Longitudinal profile of a stream:

The longitudinal profile of a stream is a graphic outline of the stream's gradient along it's course. The longitudinal course of a river from its source to mouth is called longitudinal or simply long profile or valley thalweg. It provides information of the elevation of the stream bed at any location, the elevation being measured with respect to some fixed datum.

The longitudinal profile is a function of the following variables:

i. Discharge
ii. Load delivered to the channel.
iii. Size of debris
iv. velocity of flow
v. Flow resistance
vi. Depth of flow
vii. Width of the channel
viii. Slope of the channel.

Equation of longitudinal profile:

Assumptions:

The tendency of a stream to erode at any particular point along its profile is directly proportional to the height of the stream above the base level.

If H = Elevation above base level on MSL (ft)

X = Distance downstream from source (mile)

Then based on the assumption:

$$\frac{dH}{dx} \propto -H \quad [\text{-ve for scouring}]$$

$$\Rightarrow \frac{dH}{dx} = -bH \quad [\text{b is proportionality constant}]$$

$$\Rightarrow \frac{dH}{H} = -b.dx$$

$$\Rightarrow \ln H = -bx + \ln C \quad [\text{C is integration constant}]$$

$$\Rightarrow \ln H - \ln c = -bx$$

$$\Rightarrow \ln(H/c) = -bx$$

$$\Rightarrow H/c = e^{-bx}$$

This is the general equation of longitudinal bed profile.

Readjustment of the stream grade: A graded stream delicately adjusted to its environment of supply of water and rock waste from the upstream sources is highly sensitive to changes in those controls. Changes in climate and in land surface of the water shade bring changes in discharge and load at downstream points and these changes in turn require channel readjustment.

Effect of increase in bed load:

If sediment comes from upstream carrying by the stream current then bed load increases and it crosses the limit then the river bed will be aggraded i.e. level increased.

Increase of bed load beyond stream capacity → Accumulation of coarse sediment on the stream bed → elevation of stream bed → Aggradation.

As consequence of aggradation:

In the upstream direction: Reduces the channel slope in the u/s direction → Reduction of stream capacity in the reach → accumulation of bed materials in the u/s direction.

In the downstream direction: The channel slope is increased → velocity increases → more bed materials aggraded downstream.

Aggradation changes the channel cross section from a narrow and deep form to a wide and shallow one.

Effect of decrease in bed load: This change can come along a number of ways:

- Reforestation of an abandoned farmland.
- Building of dam, trapping sediment in the upstream reservoir.

Rejuvenation: Rejuvenation is 'sudden and phenomenal increase in the erosive power of the streams and consequent accelerated rate of downcutting caused by steepening of channel gradient either due to negative change in sea level or upliftment of land mass in a river course.

CHANNEL MORPHOLOGY

Channel morphology includes the consideration of:

1. Channel geometry:
   - a. channel length
   - b. channel width
   - c. channel depth
   - d. Wetted perimeter
   - e. channel slope
   - f. channel bends or meander
2. Channel fluid dynamics:
   - a. Discharge
   - b. Velocity
3. Hydraulic geometry
4. Channel types
5. Channel bed topography
6. Channel patterns etc.

Channel geometry:

Channel geometry representing the size and shape of cross sectional channel form.

River channel:

A river channel represents water course of a river confined within the limits of valley walls on both the sides.

Effluent streams: Rivers in humid regions which receive contributions of groundwater are called effluent streams.

Influent streams: Rivers in arid regions generally lose water to the ground in addition to losing it by evaporation and often they dry up entirely without reaching the sea, are called influent streams.

Bed load: The coarser materials lying on the river bed are called bed load.

Hydrolic geometry: The analysis of the relationships among stream discharge, velocity, channel shape, sediment load, channel width, depth, slope etc is called hydrolic geometry of a river channel.

Stream dischange, $Q = w \times d \times v$

Where, w = channel width

d = average channel depth

v = average velocity.

Channel bed topography: The bed topography of a river channel refers to configuration of the river beds in terms of positive and negetive features e.g. presence or absence of riffles and pools sand bars and sand islands, shoals, sand dunes etc.

Channel types: on the basis of lithological characteristics of the region through which the river has developed its course, the river channels are divided into two broad categories:

1. Bedrock channel: [2008]

Bedrock channels are also called erosional channels and simply channels as they have been developed on well consolidated rocks popularly called as bedrock. They occur whenever potential rates of removal exceed sediment supply. in high mountain areas with steep slopes, glaciated hardrock regions and in areas undergoing active tectonic uplift.

2. Alluvial channel: [2008]

Alluvial channels develop in the regions of sedimentation or alluviation that is where thick deposits of sediments of mostly fluvial origin have taken place. They also develop in the broad coastal plains having fluvial as well as marine deposits.

Alluvial channels are characterized by degradation aggradation and again degradation. This means the deposited materials are reworked by the channels during coming wet season.

Types of alluvial channels:

1. Suspended load channels: The channel with straight course and uniform depth.

2. Mixed load straight channel: The channel with sinuous thalweg and small coarse sediment.

3. Suspended load channel: The channel with high sinuosity, uniform channel width and stable banks.

4. Meander braided transition channel: Characterised by large sediment load having greater proportion of sand, gravel and cobble, wide and shallow channel, variable channel width, chute cutoffs and shifts in thalweg and meander.

5. Bed-load channel: representing bar-braided stream, is characterized by unstable condition, large sediment load of fairly larger size and coarse in texture, erodible bank materials, migrating gravel bars and islands etc.

Shape of stream channel:

Shape refers to the configuration or form of the channel in cross-section. The shape of the channel is determined by the form ratio.

Form ratio:

The ratio of water surface width to mean depth is known as form ratio.

Four generalisations regarding the channel shape can be made:

i. Most rivers have roughly parabolic cross-sections.

ii. River channels are asymmetrical at bends.

iii. Rivers increase their width-depth ratio in the downstream direction.

iv. Big rivers have relatively large width-depth ratio.

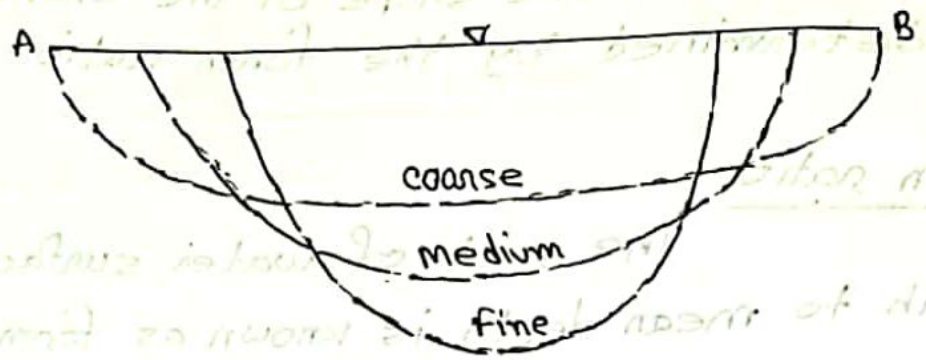
The shape of a channel at a given cross section is a function of three variables:

i. The discharge and its variations

ii. The quantity and nature of the sediment.

iii. The nature of materials through which the river flows.

Describe the effect of sediment size on channel section with neat sketch: [2007, 2013



Sediment size governs the shape of channel section. The natural channels have a tendency to assume a semi-elliptical shape. The coarser the sediment flatter is the semi-ellipse and greater is the width at the water surface. Finer the sediment more nearly does the section approximate to a semi-circle. The medium size of sediment forms elliptical shape.

Channel pattern or planform:

The channel pattern or planform refers to the shape or configuration of a single river as seen from the sky.

Types of channel pattern:

There are usually five types of channel pattern.

1. Straight
2. Sinuous
3. Meandering
4. Braided
5. Anastomosing or anabranching.

Straight channel:

Channels are defined as straight when sinuosity index is less than 1.05. In natural system straight channel may be possible up to the stretches of 100m or so.

Sinuous channel:

Channels are defined as sinuous when sinuosity index is between 1.05 and 1.50.

Sinuosity: [2013, 2015]

Sinuosity is defined as the ratio between channel length and valley length.

Sinuosity index, $SI = \frac{CL}{VL}$

Tortuosity: [2013]

Tortuosity is defined as the ratio of the difference between thalweg length and valley length to the valley length. It is expressed in percentage.

$$\text{Tortuosity} = \frac{TL - VL}{VL} * 100$$

Differences between sinuosity and tortuosity:

[2009

Sinuosity	Tortuosity
Sinuosity is the ratio of channel length and valley length.	Tortuosity is the ratio of the difference between thalweg length and valley length to the valley length.
Sinuosity index, $SI = \frac{CL}{VL}$	$\text{Tortuosity} = \frac{TL-VL}{VL} \times 100$
It represents the channel pattern	Tortuos is one kind of sinousity

Channel length:

The channel length is determined along the channel between two points on a river.

Valley length:

Valley length is the straight line distance between two points on a river.

Thalweg : [2007]

Thalweg is defined as the imaginary line joining maximum depth point within a water course system. It is almost always the line of fastest flow in any river.

Difference between thalweg length and valley length. [2006]

Thalweg length	Valley length
It is an imaginary line joining the maximum depth point within a watercourse.	It is the straight line distance between two points on a river
It is a zig-zag line	It is a straight line

Meandering channel:

A meander is a bend in a stream. A straight channel having sinuosity index more than 1.50 is defined as meandering channel. It is the most common channel pattern to be found anywhere along the longitudinal course of a river mainly alluvial rivers.

Classification of meander: [2007, 2009, 2012]

Meanders have been classified by Chitale as

1. Regular meander:

It is a train of bends of nearly the same curvature and frequency.

2. Irregular meander:

It is deformed in shape and may vary in amplitude and frequency.

3. Simple meander:

It has bends with a single radius of curvature.

4. Compound meander:

Each bend in compound meander is made up of segments of different radius and varying angles.

Differences between regular and irregular meander. [2006]

Regular meander	Irregular meander
Bends of nearly the same curvature	Bends are variable curvature.
Same frequency	variable frequency
Same amplitude	variable amplitude

Cutoff:

A cutoff occurs when the neck between river meanders is eroded away and the meanders join to shorten the length of the channel.

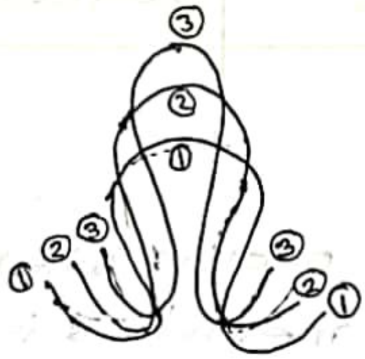
Natural cutoff:

A cutoff occurs when the neck between river meanders is eroded away naturally and the meanders join to shorten the length of the channel is called natural cutoff.

Types of cutoff: cutoffs are generally two types.

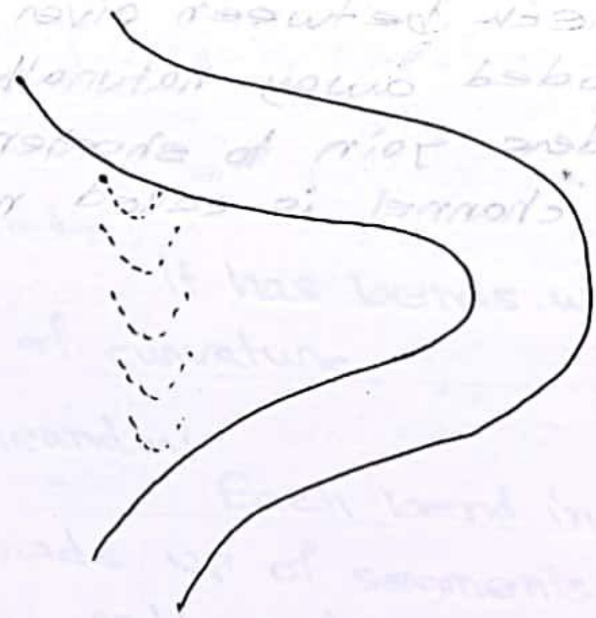
1. Loop or neck cutoff: [2006, 2010]

Loop or neck cutoffs occur when progressive bank erosion at the neck of acute bends. These are more common.



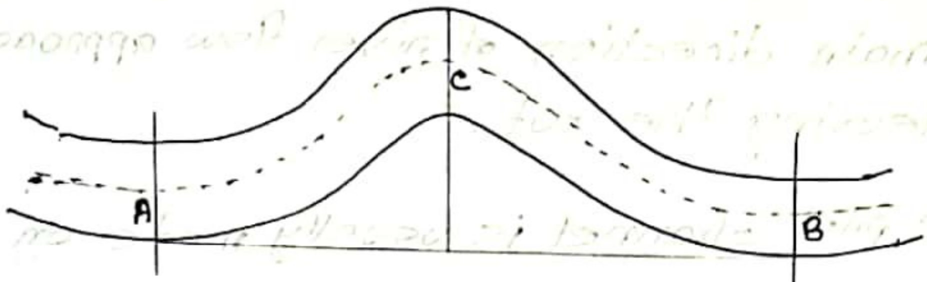
2. Chute cutoff: [2010]

A chute cutoff occurs normally across the base of a flat meander and is less common.



Cutoff ratio: [2006, 2007, 2008, 2012, 2013, 2014, 2015]

Cutoff ratio is defined as the ratio of length of the bend to that of the chord. i.e. ACB/AB in the following figure. This ratio varies according to the type of cutoff and characteristics of the river.



Artificial cutoff: [2014, 2015]

Many times artificial cutoffs are executed on alluvial streams in order to reduce flood heights and flood periods. Also artificial cutoffs have been used to shorten the travel distance and increase ease of maneuvering along the bend during navigation.

Differences between neck and chute cutoff

[2009]

Neck cutoff	Chute cutoff
Occur when progressive bank erosion at the neck of acute bends.	Occurs normally across the base of a flat meander
It is more common	It is less common

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Recommendation made by Pickle on procedure which should be considered for the design and execution of artificial cutoff.

[2007, 2008, 2010, 2011, 2012, 2013, 2015, 2016]

I. The pilot channel should be tangential to the main direction of river flow approaching and leaving the cut.

II. The pilot channel is usually made on a slight curve, the curvature being less than the dominant curvature of the river itself.

III. Entrance to the pilot channel is made bell mouthed.

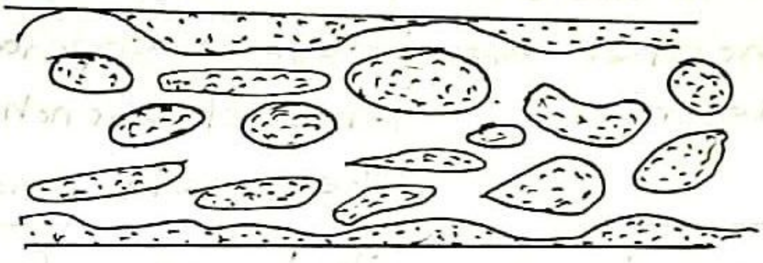
IV. For coarseness of the material or of low shear stress the cut should be excavated to mean river cross section.

V. The width of the pilot cut is unimportant as the cut ultimately widens due to scouring.

VI. When a series of cutoffs is to be made the work should progress from downstream to the upstream.

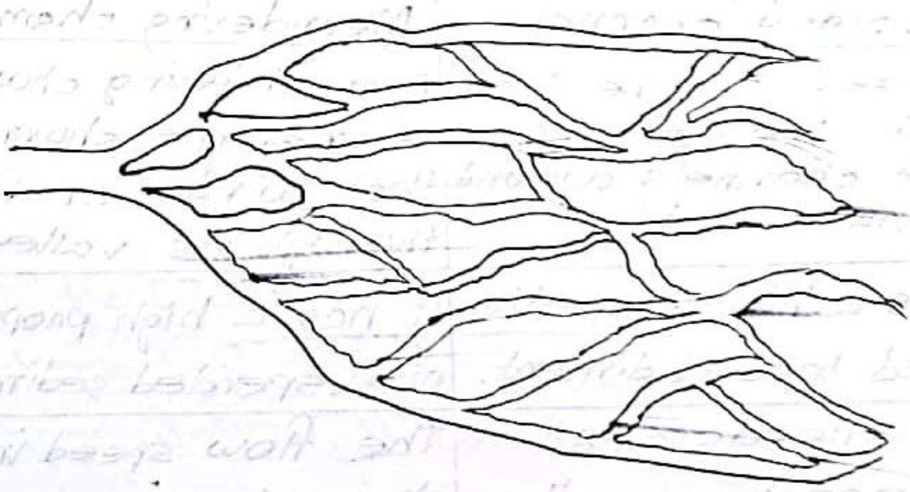
Braided channel:

A braided channel can be defined as one which flow in two or more channels around alluvial islands.



Distributary channel:

Distributary channel is one in which several seperate channel branch out of the parent stream.



Braiding index: [2015]

Braiding index is defined as the ratio of mean number of active channels or braid bars to the cross-sectional transect.

$$BI = \frac{\text{Mean number of active channels}}{\text{cross-sectional transects}}.$$

Differences between braided and distributary channel. [2006, 2007]

Braided channel	Distributary channel
It flows in two or more channels around alluvial island	It is one in which several seperate channel branch out of the parent stream
It does not diverge from main channel	It diverges from main channel

Differences between braided and meandering channels: [2013, 2015]

Braided channel	Meandering channel
Braided channel is one which flows in two or more channels around alluvial island.	A meandering channel is a single channel that winds snakelike through its valley.
It has a high proportion of bed load sediment.	It has a high proportion of suspended sediment.
Flow speeds and transport capacity vary dramatically.	The flow speed in the channel varies with the geometry of the meander.

Causes for the development of braided pattern of a river. [2012, 2013]

i. Incompetence of the river to transport bedload.
ii. High single channel resistance to flow to move the bedload.
iii. Formation of bars and islands
iv. Highly erodable banks.
v. Fluctuations in discharge change
vi. Sediment transport, bank erosion and channel scour.
vi. steep channel gradient
v. Abundant and coarse bedload etc.

Characteristics of braided pattern: [2008, 2010, 2011, 2012]

1. Aggradation: Since braided pattern emerges when bed load transport is heavy, braiding of channels is often associated with tendency for aggradation. It needs not always experience aggradation.

2. Channel alignment: Heavy bedload, generating a wide and shallow cross-section, was seen to be the basic reason for formation of braiding pattern. Associated characteristics

were found to be steeper slope, coarser bed material and higher velocities.

3. Movement of Islands:

Islands in braided rivers get eroded on their upstream faces and build up on the downstream faces. The Islands therefore appear to be unstable and moving downstream.

4. Bank erosion:

Islands in some of the braided rivers have a tendency to movement of islands the channel along the bank gets squeezed causing increase in dischange concentration thus leading to local bank erosion.

Anastomosing channel: [2013, 2015]

Anastomosing channel is one where there are many channel but they are stable and retain their identities with changing dischange and time. The sinuosity of this channel is greater than 2 and depth ratio is less than 10.

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Anabranching pattern:

Anabranching channel pattern is one where the anabranches (offshoots) rejoin the original trunk or unite with a next-neighbouring trunk, sometimes after a distance of tens of miles.

Variables that are necessary to know while studying the behaviour of alluvial fans. [2002]

On variables in stream problems:

While studying the behaviour of alluvial streams it is necessary to know the important variables that are involved in the phenomenon. leaving aside the variables which characterize the sediment and water and remain essentially constant (i.e. ρ, g and temperature), the more important variables are:

1. Water discharge, Q
2. Bed material transport rate Q_T
3. Representative size of the bed material, d
4. Stream slope, S
5. Width to depth ratio, r (characterizing the shape of cross section).
6. Ratio of stream mileage to valley mileage, M_1 (characterising the shape of the stream in plan i.e. meander pattern).

alluvi

It is necessary to find out which of the above variables are independent and which are dependent. Of these variables r and M_i are certainly dependent variables whereas Q & d are certainly independent variables.

In the upper course of the stream the slope of the land and hence the slope of the stream is determined by geological factors and S can be treated as independent variable so far as stream behaviour is concerned. Thus Q, S and d determine the magnitude of sediment transport rate Q_T in the upper course of the stream and Q_T becomes a dependent variable. In the lower course of the stream Q, Q_T and d become the independent variables and hence the slope S becomes a dependent variable along with r and M_i.

Dominant discharge of river flow. [2006, 2007, 2009, 2011]

The flow in alluvial streams differs from that in regime channels in several respects. The most important difference between them that while regime channels are designed to carry a fairly constant discharge, alluvial streams carry extremely varying discharge and sediment loads.

The wide variation in stream flow makes it difficult to choose a representative discharge in studying the stream characteristics. Different methods have been suggested for the choice of a representative discharge.

Inglis introduced the concept of dominant discharge. According to him there is a dominant discharge and gradient to which a channel returns annually. At this discharge equilibrium is most closely approached and the tendency to change is the least. In other words dominant discharge is that hypothetical steady discharge which would produce the same result (in terms of average channel dimensions) as the actual varying discharge.

Blench designates that discharge as dominant discharge which is equalled or exceeded 50% of the time.

The U.S.B.R. (United States Bureau of Reclamation) defines the dominant discharge as the discharge that will carry the greatest sediment load of material coarser than 0.0625 mm with respect to time.

A little reflection will show that the dominant discharge which determines the average channel dimensions need not correspond to the steady discharge which would yield the same annual sediment transport as that due to the varying discharge. From this point of view the concept of dominant discharge is of questionable significane.

Dominant discharge may be defined as that discharge which transports most bed sediment in a stream that is close to steady state condition. It is also called river shaping channel discharge

<u>Bed generative discharge introduced by Schaffernak</u>: [2007, 2012, 2013, 2016]

Schaffernak has introduced the term bed generative discharge which is defined as the discharge that transports the largest volume of coarse material.

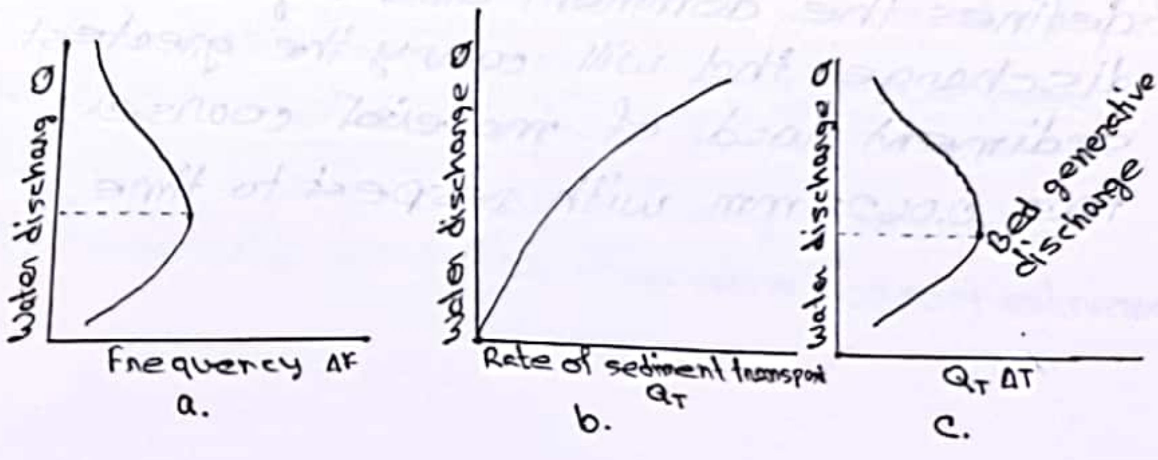


Figure. a shows the frequency-discharge curve for a given stream. Figure b shows the relationship between water discharge and sediment transport. In figure c the abscissa is obtained by multiplying the frequency ΔF of a particular discharge Q by the corresponding sediment transport rate Q_T. The discharge which gives the maximum value of $Q_T \Delta F$ is the bed generative discharge and is supposed to influence the channel geometry. NEDCO recommends finding the depth D_o corresponding to the dominant discharge using the equation

$$D_o \int_0^T Q_B dt = \int_0^T Q_B D \, dt$$

$$\Rightarrow D_o = \frac{\int_0^T Q_B D \, dt}{\int_0^T Q_B \, dt}$$

In which Q_B is the bed load transport rate. Gondolfo found that the bed generative discharge is greater than the discharge corresponding to the average sediment transport rate and that the latter is greater than the mean annual discharge.

CYCLE OF EROSION

Forces affect the earth surface: The earth surface is affected by two types of forces.

i. Endogenete force

ii. Exogenetic force.

Endogenetic force: Endogenetic forces create vertical irregularities on the earths surface by forming several types of relief features of different dimensions.

Exogenetic force: Exogenetic processes originating from the atmosphere (rivers, wind, glaciers, sea waves, groundwater, periglacial processes etc) try to remove the vertical irregularities created by the endogenetic forces and ultimately become successful in bringing down the relief to low featureless plain called as a peneplain.

Various stages of streams or rivers:

1. Youth stage:

A young stream is always able to erod its channel in the vertical direction. the slope of a young stream is always greater than the slope necessary to carry the sediment load coming into it.

2. Mature stream: [2006, 2007, 2008, 2010, 2011, 2012]

A mature stream is one in which over a period of years slope is delicately adjusted to provide with the available discharge and with prevailing channel characteristics just the velocity required for the transportation of the load supplied from the drainage basin. The mature stream is a system in equilibrium.

Mature stream is also known as a graded stream, poised stream, balanced stream, stream in regime or stream in equilibrium.

Characteristics of mature stream: [2006, 2007, 2008, 2009, 2010, 2011, 2012, 2015

i. Flood plain with natural levees.

ii. Meanders with abandoned meander scrolls, cut off and oxbow lakes.

iii. Width of the valley equal to or greater than width of meander belt.

iv. No rapids or falls.

v. Slow moving currents of muddy water.

vi. Subdued valley walls with deep soil cover and few rock outcrops

vii. No lakes except oxbow lakes.

3. Old stage:

A stream whose tributaries are all mature or graded is known as an old stream. There are no significant changes in the characteristics of mature and old rivers.

FLUVIAL GEOMORPHOLOGY

Fluvial process :

The running waters which include overland flow or surface runoff and stream flow shape the fluvial landforms are called fluvial process.

The geological works of fluvial processes are called three phase work comprising

i. Erosion

ii. Transportation and

iii. Deposition

Fluvial landforms :

The landforms either carved out due to erosion or built up due to deposition by running water are called fluvial landforms.

The fluvial landforms are divided into two major groups

i. Erosional landform and

ii. Depositional landform.

Erosional landform :

The landforms resulting from progressive removal of the bedrock mass are called erosional landforms.

Various landforms are:

i. various types of valley
ii. pot holes
iii. Rapids and waterfalls
iv. Structural benches
v. Terraces
vi. Meanders etc.

Depositional landforms: The landforms shaped by the deposition of different types of eroded materials become depositional landforms.

Various depositional landforms are

i. Alluvial fans and cones
ii. Natural levees
iii. Flood plains
iv. Deltas etc.

Pools and riffles: [2013]

Pools and riffles along the stream channel are the smallest erosional features in the crystalline rock areas.

Formation of pools and riffles:

These are formed due to the erosion of the sediment dunes in the river beds by the stream flow. During the low flow resistance to flow is great and the rate of sediment transport is reduced then the formation of pools and riffles are maximum. These are temporary features as during high flow the bed surface becomes smooth or plain.

Differences between pools and riffles: [2009]

Pools	Riffles
A pool is characterised by a water surface profile less than the mean channel gradient.	A riffle is characterised by a water surface slope steeper than the mean channel gradient.
It develops at concave bank.	It develops at cross-over of the channel.
The channel cross-section is asymmetrical at pools.	The channe cross-section is symmetrical at riffles.
The chennel depth is greater at pools than at riffles.	The channel depth is lesser at riffles than at pools.

Effects of river degradation : [2006, 2007, 2011, 2013]

I. For a given discharge the tail water level is lowered as a result of degradation.

II. The difference between head and tail water level can be known.

III. Increase in effective head means that greater head is available for power generation in case of a hydroelectric scheme.

IV. Lowering of the water level due to degradation reduces the height of ground water table in the adjoining areas.

V. Lowering of the stream bed by degradation increases the capacity of the river channel to carry the flood flow.

VI. Lowering of water level may lead to deterioration of piling.

VII. Degradation makes the diversion of water for irrigation more difficult.

Backswamp:

Backswamp is a type of depositional environment commonly found in a floodplain. It is where deposits of fine silts and clays settle after a flood. Backswamps usually lie behind a stream's natural levee. It is an old oxbow lake which changes by different manmade and natural activities.

Activities of running water:

The water that flows along the river does the following works:

1. It transports the debris
2. It erodes the river channel deeper into the land.
3. It deposits sediments at various points along the valley or delivers them to lakes or oceans.

River transportation:

River transportation is the ability of river to carry along the particles that a stream picks up directly from its own channel or that is supplied to it by slope wash, tributaries or mass movement.

Factors affecting the transportation power of river: [EC]

1. Size of particle to be carried.
2. Volume of total load
3. Velocity of river at specific location.

Load of river: The amount of material that a river carries at any time is called its load. The unit of a river load is ton. The load of a river varies at different times.

Capacity: The total amount of material in tons a river is capable of carrying under any given set of conditions is called the capacity of the river. Capacity of a river varies approximately with the third power of the velocity if a fair proportion of all grain sizes are available, with a higher power if all the materials are fine grained and with a lower power if the material is coarse. Velocity and particle size are critical parameters of river bank protection.

Competence: The maximum size of particles that a river can carry is called its competence. The competence of a river is a statement of its ability to move materials in terms of material size. Competence is a function of velocity only. The diameter of particle that a river can move varies approximately with the square of the stream velocity.

Classification of load:

1. Dissolved load:

Dissolve loads are the soluble materials and are carried in solution in the form of ions. The amount of dissolved load depends upon:

i. Climate
ii. Season and
iii. Geologic settings.

2. Suspended load:

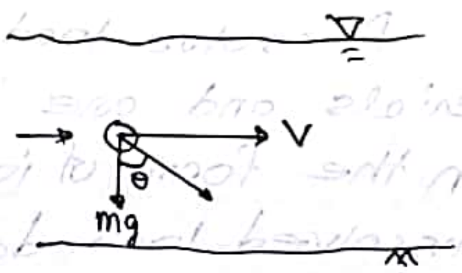
This is the load carried mechanically as sediment. These are the particles of solid matter that are swept along in the turbulent current of the stream and remain in the suspension. The amount of this load depends upon :

i. intensity of turbulence of water and

ii. terminal velocity of each individual particle.

3. Bed load :

Bed loads are the solid particles which moving along the riverbed. Bed load mainly consists of gravel and sand



In the case of bed load θ tends to zero or very small.

Methods of transportation work of rivers: [2009, 2014, 2015] [EC]

Rivers transport their load in four different ways -

1. By traction:
The heavier and large rock fragments like gravel, pebbles etc are forced by the flow of water to roll on the floor to the channel. These fragments can be seen rolling, slipping and bumping. This is known as traction.

2. By saltation:
The fragments of the rocks move onward by jumping continuously. This is called saltation.

3. By suspension: When the rock fragments fall in the stream their weight is reduced by the buoyancy of water. Usually the relative density of rock particles is 2.5. Their weight in the water is reduced by 2/5. The reduced weight of the fragments keeps them in suspension. The suspended rock particles are clay or silt.

4. By solution: some parts of the rock fragments are dissolved in the stream water.

Differences between competence and capacity of a river: [2006, 2007, 2008, 2009, 2010, 2013, 2015

Competence	Capacity
The competence of a river is measured by the largest rock fragment that stream can transport	The capacity of a stream can be measured by the total load of the stream.
The competence (c) is proportional to the sixth power of the velocity of a stream i.e. $c \propto v^6$	The capacity (c) is proportional to the third power of the velocity of a stream for ordinary type of rock fragments
Competence measures size of particles comprising sediment.	Capacity measures quantity of sediment.
For greater competence the larger and heavier fragments will be transported	For more capacity total quantity of sediment will be transported.

Alluvial fans: [2008, 2009, 2011]

Alluvial fans are defined as the fan shaped deposits of water transported material like gravel, sand and silt. These materials are called alluvium.

Formation of alluvial fans : [2006, 2007]

In the upper reach of a river in the mountainous region, the slopes are steep and the flow has a high velocity. Sediment concentration is therefore also high. At the foothills the river descends into the plains where the slope suddenly becomes flat and the velocity drops. As a result the capacity of flow to carry sediment reduces appreciably. The sediment then deposits and causes bed aggradation. When the bed is raised, the river shifts laterally. By this process a cone shaped delta is built by the river which presents the shape of a fan. This formation is known by the term alluvial fan.

Geographical importance of alluvial fan: [2015]

The following describes the geographical importance of alluvial fans:

1. Cities develop near the peripheries of alluvial fans.

ii. Water is available for irrigation from these fans.

Scanned with CamScanner

iii. The water of the fans goes to the lower layers by seepage. Water can be pumped up from these layers even when there is no water available on the surface of the fans.

iv. Fertile soil is available in these fans in the semi arid fans. Agriculture is developed in these fans.

Allovial cones:

Many times the alluvial fans increase in height by the deposition of the sediment of the fans and their slope becomes steeper. Such formations are called alluvial cones.

Differences between alluvial fans and alluvial cones. [2015

Alluvial fans	Alluvial cones
The slope of fans are much little than cone	The slope of cone is greater than fan
Larger fans have average slope of less than 1° Smaller fans have average slope of 5°	Cones have the average slope of 15°
Alluvial fans are made of finer material.	Coarser material than fans

Flood plain:

A flood plain is the relatively flat area that borders a stream which is periodically inundated with water during high flow periods.

The area in which a stream spreads its sediment is called flood plain.

These plain have become very fertile as a result of fresh deposition of sediment continuously. Floodplain agriculture has given rise to many of great world civilizations.

Types of deposits in flood plain:

Mainly three types of deposits are found in flood plain.

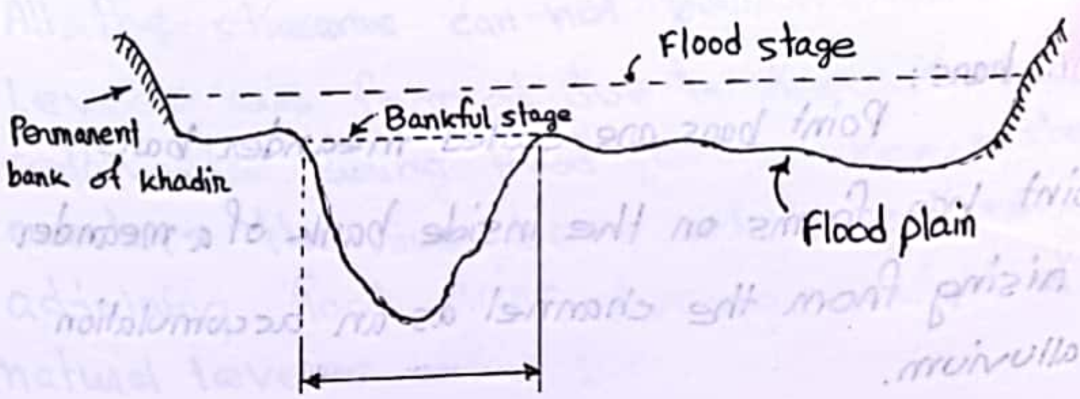
i. Colluvium

ii. Channel deposits

iii. Overbank deposits.

Typical cross-section of a river with flood plain:

[2006, 2007, 2010, 2012, 2014]



Major features are found in flood plain: [2005]

Major flood plain features are

i. Natural levees
ii. Backswamps
iii. Sloughs
iv. Meander scroll
v. Crevasses and splays
vi. Flood plain placers. etc.

Bars (চড়):

Along the stream channel are likely to be found numerous deposits of sand and gravel commonly known as bars.

A bar in a river is an elevated region of sediment (such as sand or gravel) that has been deposited by the flow. When deposition occurs at the middle of the river then it is bars but when at the banks then it is shore.

Types of bars:

1. channel bars:

Channel bars are located in the stream course and are perhaps most characteristic of braided streams.

2. Point bars:

Point bars are called meander bars.

A point bar forms on the inside bank of a meander and rising from the channel as an accumulation of alluvium.

3. Longitudinal bars: It is common in gravel bed rivers.

4. Transverse bars: It occur from one bank by avalanche and extend downstream and lateral margins.

5. Diagonal bars: It is aligned perpendicular to the flow and are formed of horizontal gravel strata.

6. Linguoid bars: Linguoid bars which are large-scale ripple-like forms in sandy sediments, these migrate downstream.

Natural levees: [2009, 2011, 2016]
A natural levee is a narrow ridge of alluvium deposited at the side of the channel. They are highest near the river and slope gradually away from it.
All the streams can not build natural levees.
Levees are formed due to deposition of sediments during flood periods when water overtops the river banks and spread over adjoining flood plains. Average height of natural levees within 10m.

Formation of natural levees: [2005]

During flood periods the whole plain from one valley wall to the other is under water and the water current is most rapid along the deep line of river channel. Silt bearing water spreads out and mingles with shallow flood waters on either side. It quickly loses its velocity and much of the silt and sand settle along both sides of the river channel. During flood period such type of deposition occurs year after year and as a result a slightly higher ground is formed known as natural levees on both sides of the river.

Delta:

The depositional feature of almost triangular shape at the mouth of a river debouching either in a lake or a sea is called delta. The size of delta of major and small rivers all over the world varies from a few km^2 to thousands of km^2. The shape of delta also varies from one river to the other.

Factors on which delta size depends:

The size of delta depends on the

i. rock characteristics

ii. Vegetal cover

iii. Rate of erosion

iv. Amount of annual rainfall etc.

Ideal conditions for delta formation: [2007, 2008, 2010, 2011, 2015

The ideal conditions for the formation and growth of delta include.

i. Suitable place in the form of shallow sea and lake shores.

ii. Long course of the rivers

iii. Medium size of sediment

iv. Large supply of sediment

v. Relatively calm sea at the mouth of the river.

vi. Stable condition of sea coast and oceanic bottom.

vii. Accelerated rate of erosion in the catchment area of the concerned river.

Differences between alluvial fans and delta:

Alluvial fans	Delta
The flow of water in an alluvial fan is suddenly decreased.	The flow of water decreases slowly
The upper part of the alluvial fan is less distinct.	The upper part of delta is more distinct
No limit deposition	Limit deposition

Causes of autogenic instability of river:

[2006, 2007, 2008, 2009, 2010, 2015, 2016]

i. Aggradation caused by the formation of alluvial fan.

ii. Erosion on concave bank

iii. Sediment deposition along convex bank.

iv. Formation of hairpin bends in cut off.

v. Flattening of slope due to extension of delta.

vi. Shoaling due to flocculation.

Alluvium:

The loose sedimentary materials make alluvial channels are known as the alluvium. It consists of clay, silt, sand or gravel in various layered arrangements. It is very fertile and alluvium deposition can't occur without flood.

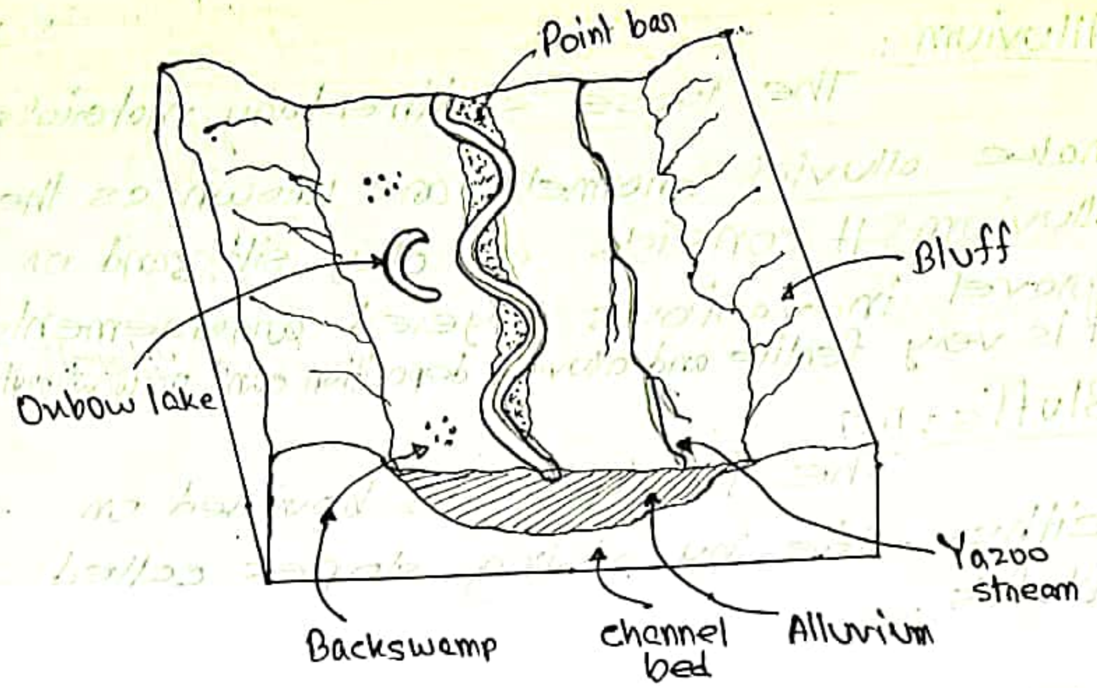
Bluffs: [EC]

The floodplain is bounded on either side by rising slopes called bluffs.

Oxbow lake: [EC]

An oxbow lake is a U-shaped lake that forms when a wide meander of a river is cut off and creating a free standing body of water. The oxbow lake is gradually filled with fine sediment brought in during high floods and with organic matter produced by aquatic plants. Eventually the oxbows are converted into swamps.

Yazoo stream: A yazoo stream is a tributary stream that lies within a single flood plain with a larger river and runs parallel to the river for a long distance and eventually joins it downstream.


Point bar
Bluff
Oxbow lake
Yazoo stream
Backswamp
channel bed
Alluvium